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AN AUTOMATED SYSTEM FOR COLLECTING, PROCESSING, AND DISPLAYING --ETC(U)

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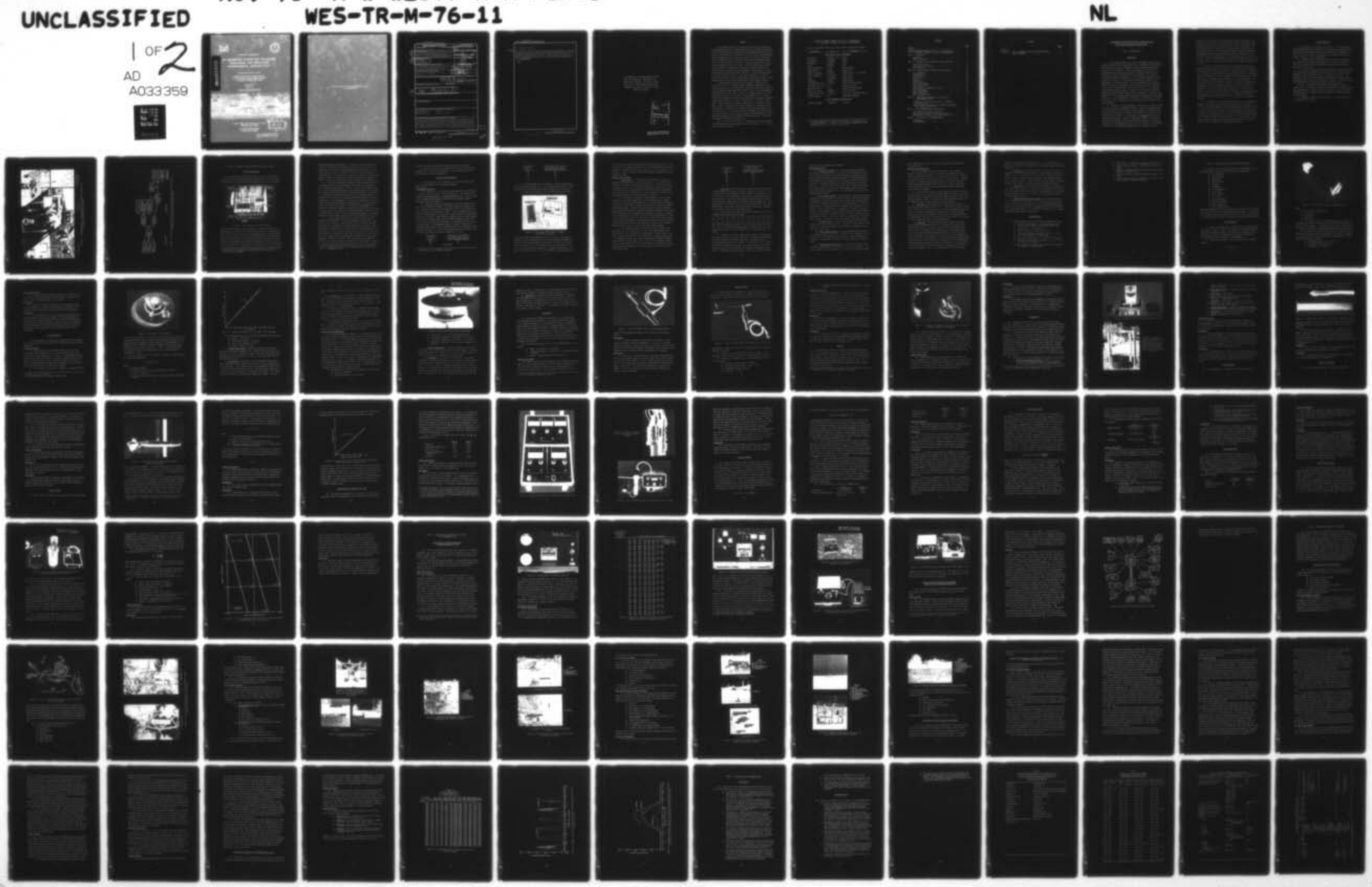

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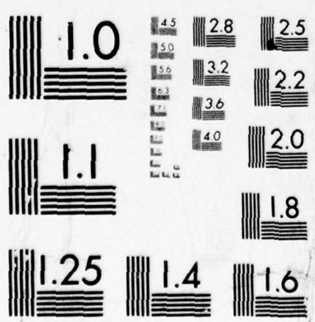

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TECHNICAL REPORT M-76-11

AN AUTOMATED SYSTEM FOR COLLECTING PROCESSING, AND DISPLAYING ENVIRONMENTAL BASELINE DATA

by

Harold W. West, Herman M. Floyd

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November 1976

Final Report

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20. ABSTRACT (*Continue on reverse side if necessary and identify by block number*)

A system for automated collecting, processing, and displaying of environmental baseline data is described. The functions of the system, consisting of data collection with an automated field station, data processing, and data display options, are discussed. Also included are descriptions of the environmental sensors that are being used with the field station. Data that were obtained with the system at 15-, 30-, and 60-min sampling intervals

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20. ABSTRACT (Continued).

cont.
over a period of several months at Pine Bluff Arsenal, Arkansas, Fort Carson, Colorado, Fort McClellan, Alabama, Upper Blakely Island near Mobile, Alabama, and Satartia, Mississippi, are analyzed. Example environmental data are presented in computer formats available with the system. An estimated cost (1976) of the automated field station and selected array of sensors is provided. ~~(Appendix A).~~

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PREFACE

The automated system for collecting, processing, and displaying environmental baseline data described herein was developed under Department of the Army Project 4A762720A896, "Environmental Quality for Construction and Operation of Military Facilities," Task 01, "Environmental Quality Management for Military Facilities," Work Unit 006, "Methodology for Characterization of Military Installations Environmental Baselines," sponsored by the Directorate of Military Construction, Office, Chief of Engineers (OCE), U. S. Army. This automated system supports the requirement for acquisition of quantitative data needed in the current pollution potential and environmental characteristics of Army installations and facilities (OCR 1.03.006). The OCE Technical Monitor for the work was Mr. Vincent J. Gottschalk (DAEN-MCE-D). Funds for purchase of some parts of the instrumented system and associated sensors were provided by the OCE Plant Replacement and Improvement Program.

The system was developed during the period 1 January 1974 to 30 June 1976 at the U. S. Army Engineer Waterways Experiment Station (WES) by personnel of the Environmental Systems Division (ESD), Mobility and Environmental Systems Laboratory (MESL), and of the Instrumentation Services Division (ISD), WES. The work was conducted under the direct supervision of Messrs. H. W. West, Project Manager, and J. K. Stoll, Chief, Environmental Simulation Branch (ESB), ESD, and under the general supervision of Messrs. B. O. Benn, Chief, ESD; W. E. Grabau, formerly Chief of ESD, now special assistant, MESL; and W. G. Shockley, Chief, MESL. Leach Corporation, now Lockheed Electronics Corporation, Azusa, California, was responsible for the final design and fabrication of the field station. Mr. H. M. Floyd, ISD, was responsible for interfacing the various sensors with the field station, and Miss Margaret H. Smith, ESB, was responsible for the system software development. This report was prepared by Messrs. West and Floyd.

COL G. H. Hilt, CE, and COL J. L. Cannon, CE, were the Directors of WES during the study and preparation of the report. Mr. F. R. Brown was the Technical Director.

CONVERSION FACTORS, METRIC (SI) TO U. S. CUSTOMARY AND U. S. CUSTOMARY TO METRIC (SI) UNITS OF MEASUREMENT

Units of measurement used in this report can be converted as follows:

Multiply	By	To Obtain
	Metric (SI) to U. S. Customary	
micrometres	3.937007×10^{-5}	inches
millimetres	0.03937007	inches
centimetres	0.3937007	inches
metres	3.280839	feet
square centimetres	0.1550	square inches
square metres	10.76391	square feet
square kilometres	0.3861021	square miles (U. S. statute)
cubic centimetres	0.06102376	cubic inches
grams	0.002204622	pounds (mass)
kilograms	2.204622	pounds (mass)
milligrams per litre	0.008345	pounds per 1000 gallons
milligrams per litre	1.0	parts per million
grams per litre	8.345	pounds per 1000 gallons
metres per second	3.280839	feet per second
kilometres per hour	0.6213711	miles (U. S. statute) per hour
Celsius degrees	1.8	Fahrenheit degrees*
	U. S. Customary to Metric (SI)	
degrees (angular)	0.01745329	radians

* To obtain Fahrenheit (F) degrees from Celsius (C) readings, use the following formula: $F = 1.8(C) + 32$. To obtain Fahrenheit readings from Kelvins, use: $F = 1.8(K - 273.15) + 32$.

CONTENTS

CONTENTS

AN AUTOMATED SYSTEM FOR COLLECTING, PROCESSING, AND DISPLAYING ENVIRONMENTAL BASELINE DATA

PART I: INTRODUCTION

Background

1. Army Regulation 200-1, entitled "Environmental Quality, Environmental Protection and Enhancement," dated 7 December 1973, establishes that the Army must lead in complying with the National Environmental Protection Act (PL 91-190). The Act and derivative state and local environmental protection laws specify the maximum concentrations of pollutants that can be expelled into the environment and, therefore, establish an additional constraint on the life-cycle management of Army military facilities, i.e. the design, construction, operation, and maintenance of Army facilities. A Corps of Engineers study, entitled "Study of Impact of Environmental Consideration on Military Construction," dated 1 November 1970, identified the need for "... a system for providing necessary technology to support the environmental decision-making processes associated with life-cycle management of Army military facilities." The required long-term planning and management necessitates prediction of the environmental consequences of conducting all military activities, such as construction, troop training, waste disposal, test, and evaluation.

2. Prediction of the environmental consequences of military activities has at least two fundamental aspects. First, an understanding of the interaction of the activity and the environment is necessary; and second, the environmental conditions that prevail at the outset of the activity must be known, i.e., there must be a <u>baseline</u> from which the prediction can be made. However, environmental systems are dynamic, and baseline conditions for many environmental parameters often change several orders of magnitude with time. For this reason, the technology referred to in the preceding paragraph must be supported by data

provided by a reliable in situ instrumented system of sufficient scope, efficiency, and accuracy to describe cycles of physical, chemical, and biological processes in the aquatic and terrestrial environments. The system must be able to perform at least three basic functions more or less automatically: (a) sense an energy anomaly generated by pertinent environmental phenomena or parameters and convert the anomaly into a recordable electrical signal; (b) record the sensed signal in real time on site or transmit the information to a central recorder; and (c) store, process, retrieve, and portray the information in a manner convenient to the user.

3. Devices for sensing several of the pertinent environmental parameters are available, but it is also true that there are not devices for sensing many, perhaps the majority, of these parameters. Equipment for recording and transmitting the sensed data and methods for manipulating and portraying the recorded information can be developed, but if the system has to encompass a large number of the pertinent parameters, it would probably be very expensive. However, it seems reasonable to hope that activities at one installation would not require the simultaneous measurement of all the parameters that would have to be considered nationwide. For these reasons, the development of a low-cost system capable of measuring a selected number of different environmental parameters appears to be technically feasible. An inexpensive reliable environmental monitoring capability of this nature is badly needed by the Army.

4. In response to the need stated above, the U. S. Army Engineer Waterways Experiment Station (WES) has developed and field tested a limited, but readily expandable (provided sensors are available), system to: (a) sense and record selected environmental data on site at sampling rates selected by the user; (b) sort and store the recorded data for computer processing and retrieval; and (c) display the data in tabular or graphic formats specified by the user. To a large extent, the system operates automatically and substantially reduces the costs and errors incurred in manual data recording and handling.

Purpose and Scope

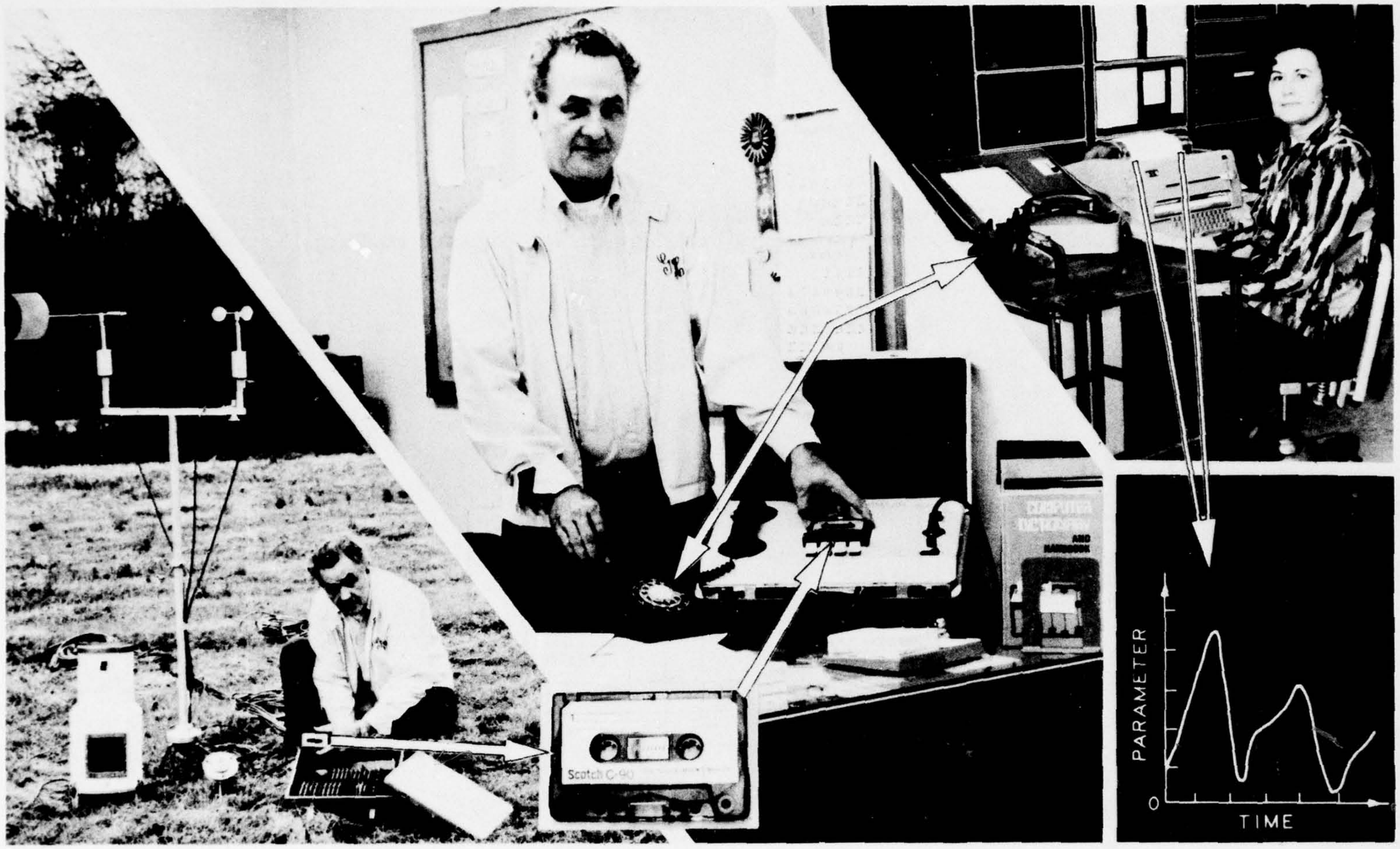
5. The purpose of this report is twofold: (a) to describe the WES automated system of instruments for collecting, processing, and displaying certain environmental baseline data; and (b) to document the field tests of the system. The system and its component parts are presented in Figures 1 and 2, respectively.

6. A portable field station (discussed in Part II) conditions and records output data from a selected set of sensors (described in Part III) in widely varying environments at sampling rates that are preselected by the user.

7. A cassette reproducer and analyzer/translator provide a record of the data that is compatible with almost any type of data reduction equipment. This translation process is described in Part IV. Also described in Part IV are the processing and display functions of the automated system, which are accomplished by computer. The digital equipment being used and the softwear capabilities are discussed.

8. Part V documents how the system performed when it was installed at five locations with different environmental conditions. Data were obtained over a period of several months at 15-, 30-, and 60-min sampling intervals. Example data are presented in formats available with the system.

9. Appendix A details the cost (1976) of the field station and a selected group of sensors.



Field Station

Translation

Data Processing
and Display

Figure 1. Automated system of instruments for collecting, processing, and portraying environmental field data

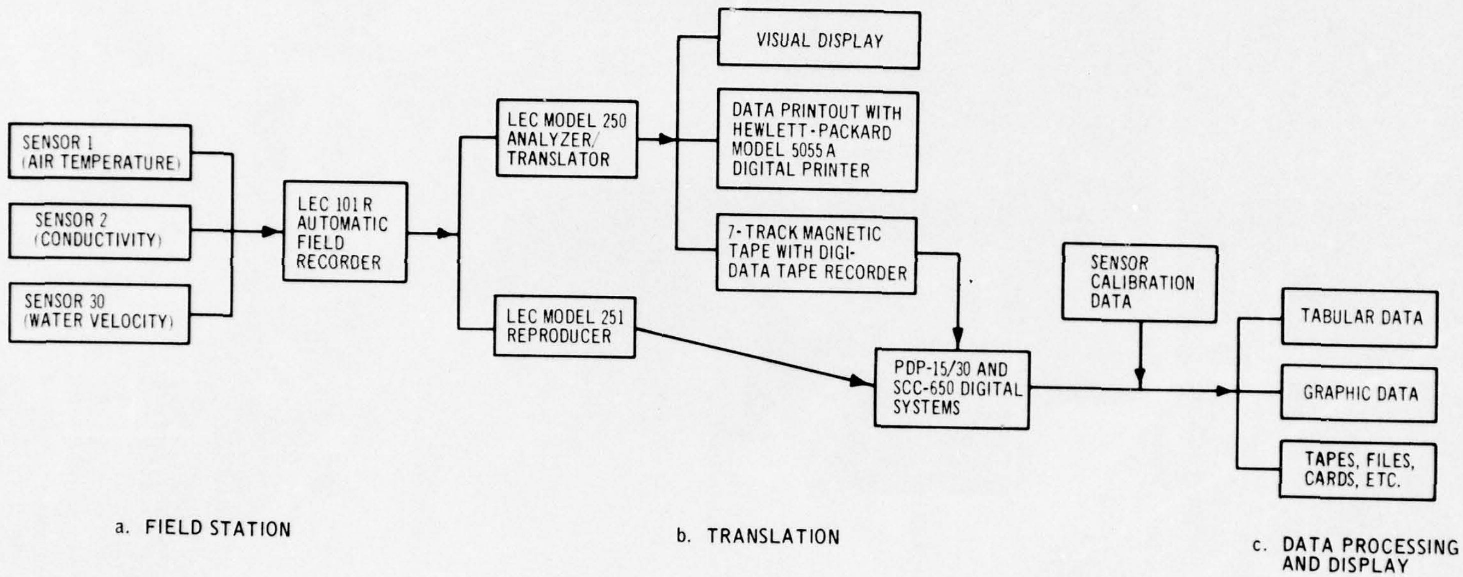


Figure 2. Diagram showing component parts of WES automated system for collecting, processing, and displaying environmental data

PART II: AUTOMATIC FIELD STATION FOR DATA ACQUISITION

General Description

10. The LEC Model 101R* field station (Figure 3) was designed to meet the need for an unattended data-gathering facility that would be capable of recording environmental parameter data on a tape recorder

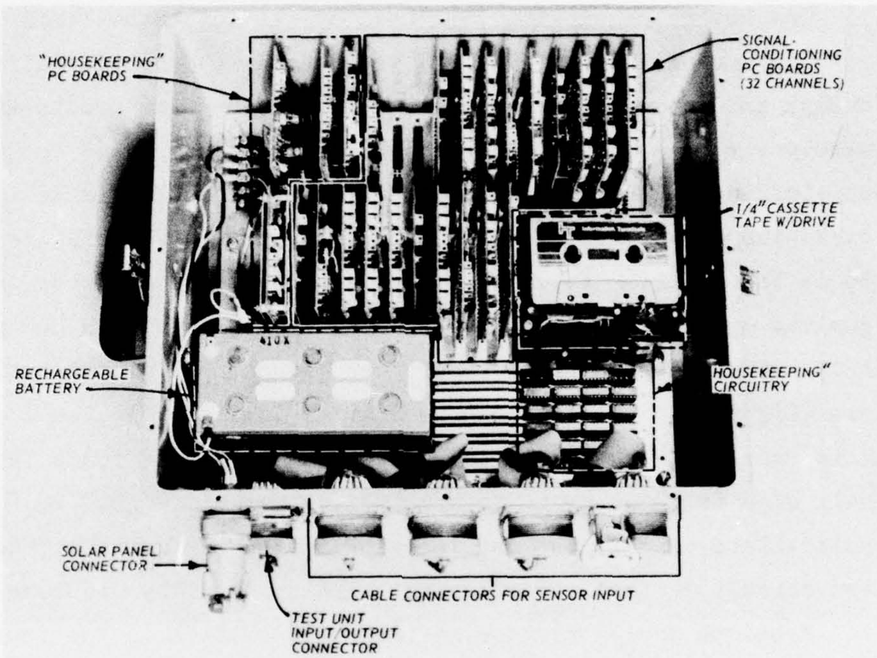


Figure 3. The LEC Model 101R field station

at preselected intervals. The components of the field station are a housekeeping circuitry, signal conditioning circuitry for 32 data channels, cassette tape recorder, and rechargeable battery. The field station can accept and condition analog and digital data from sensors that measure such parameters as wind speed and direction; air and soil temperatures; solar radiation; rainfall; evaporation; and water level, velocity, transmissivity, concentration of hydrogen ions (pH), conductivity,

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* The LEC 101R field station was designed jointly by the WES and Lockheed Electronics Company (LEC), Azusa, California, and built to specification by Lockheed.

dissolved oxygen, and temperature. The sensors that have been interfaced with the system are discussed in Part III of this report. One 32-channel field station can accommodate input from as many as 31 external sensors (one of the channels is used to record the number of interrogations). This capability, along with a selection from available sensors, permits the design of user-tailored systems that range from simple to complex and could measure many combinations of parameters.

11. The severe requirements imposed on the automated field station by the nature of its intended use were taken into consideration in its design and manufacture. Since it is to be used in remote areas and in widely varying environments, the recording electronics are housed in a dustproof, watertight, sealed, fiberglass enclosure. In addition to the exclusion of water from the inside of the housing, moisture condensation in the interior is virtually eliminated because of the insulating quality of the fiberglass. The cover is sealed with a one-piece, closed-cell, ethylene-propylene, terpolymer gasket. All input/output connectors (Figure 3) are sealed. The station is lightweight and portable to facilitate transport to remote areas over difficult terrain; its overall size is 20 by 40 by 46 cm* and its weight is 10.9 kg (24 lb). An all-solid-state circuit design, incorporating a maximum of standard integrated circuit devices, provides for high reliability and long life.

12. A unique design feature of the field station is the low standby power consumption. Low power consumption is achieved by deactivation of all circuits, except essential control circuits, during periods when no information is being conditioned and recorded. When an interrogation command occurs, the field station is automatically activated while the data are being conditioned and recorded, and deactivated upon completion of recording. Since the time required to record data is very short compared with the interrogation interval, the average power consumption is held to a minimum. This feature greatly extends the operating time between battery (paragraphs 15-18) replacements, thereby

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* A table of factors for converting metric (SI) units of measurement to U. S. customary units and U. S. customary units to metric (SI) units is presented on page 3.

reducing the service required over extended periods of operation.

13. Another factor in the ability of the station to operate over long periods of time without servicing is the storage capacity of the cassette tape cartridge (paragraph 21).

Field Station Components

14. The functions of the components of the field station (Figure 3) are described in the following paragraphs.

Power source (rechargeable battery)

15. A sealed, 12-V, 4.5 amp-hr, Globe* gel-cell battery (GC1245) is used for the power source in the field station. The battery can be recharged through many complete charge-discharge cycles. If the battery is not completely discharged during each cycle, many more charge-discharge cycles are possible.

16. Because of special calcium grids, the gel-cell battery loses very little capacity in storage. The shelf storage loss ranges from 2 to 3 percent per month at room temperature (21°C) to 10-12 percent at 35°C and less than 0.5 percent at -18°C. A fully charged battery will deliver sufficient power to operate the field station over a temperature range of -60 to +60°C. Power capacity increases above the high temperature (+60°C), decreases below the low (-60°C) temperature, and serves as a function of the rate of discharge (i.e. discharge current and the discharge time). The approximate numbers of days of operation for a 32-channel field station and 31 external sensors for the different interrogation intervals for a new, fully charged battery are tabulated below. (The data are based on an ambient temperature of +20°C.)

Interrogation Interval min	Recording Days per Battery, 32-Channel Field Station with 31 External Sensors
240	80
120	65

(Continued)

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* Globe-Union, Inc., Milwaukee, Wisconsin.

Interrogation Interval min	Recording Days per Battery, 32-Channel Field Station with 31 External Sensors
60	45
30	25
15	15
10	10
5	7
3	3

17. The field station also incorporates an input power protection circuit, which permits use of its internal battery power in normal or reverse polarity without affecting the operation of the station.

18. A solar panel (Figure 4) is available that can be added to

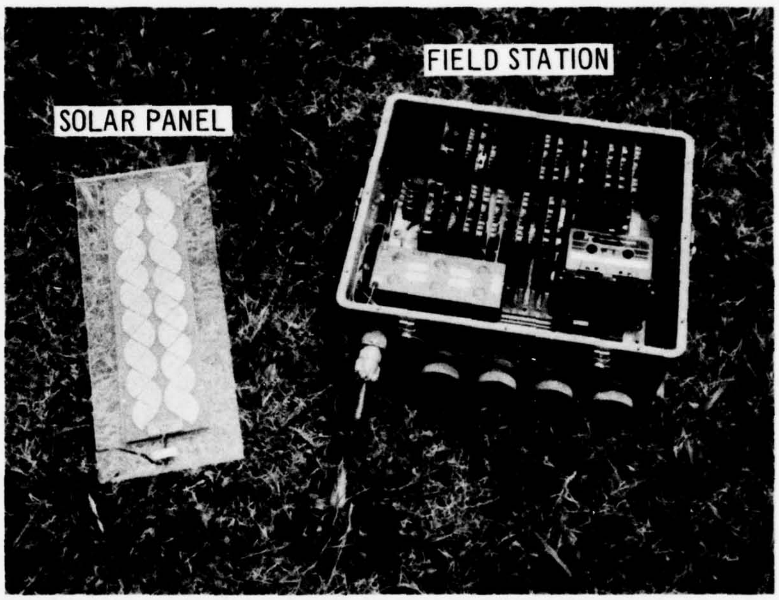

Figure 4. Solar panel being used to recharge field station battery

the field station for recharging of the 12-V battery. The panel is composed of epoxy fiberglass and silicon materials and is designed for long life under various climatic conditions. The panel will operate efficienctly from -7 to +52°C; however, the efficiency increases at the lower temperatures and decreases at the higher temperatures. The panel can deliver 125 mA, or 1.5 W, of current yielding approximately

35 to 50 Whr per week under optimum incoming radiation conditions. The orientation of the panel with respect to the incoming radiation controls the amount of charge delivered to the battery of the field station. The panel also contains a built-in diode that prevents the battery from discharging at night.

Cassette tape recorder

19. Description. The field station incorporates a specially designed, low-temperature, cassette tape recorder. The recorder has an incremental drive that packs data at a density of 120 bits per inch on two parallel tracks. The conventional pinch-roller tape drive has been eliminated, and a unique pinch-belt drive, which provides 90-deg wrap around the capstan, is incorporated. This 90-deg wrap provides positive tape-to-capstan contact over wide temperature ranges.

20. The recorder is designed to use standard, low-noise, high-quality audio tape cartridges that can be purchased almost anywhere; however, it is strongly recommended that a tape that has been designed to withstand a wide range of temperatures be used for most environmental monitoring problems. The WES is using the H-series digital cassettes manufactured by Information Terminals Corporation, Sunnyvale, California. This particular series of cassettes was designed to operate in temperatures ranging from -54 to +77°C and contains precision-machined, crowned rollers, and ribbed slip sheets that provide even winds, uniform tension, and accurate tape guidance. The conductive backing on the tape substantially reduces static electricity and debris collection and, therefore, minimizes data loss due to noise within the recording system.

21. The storage capacity of the cassette tape cartridge allows data collection over long periods of time. The approximately 85- to 90-m length of tape can store up to 200,000 bits of data; however, the rate of usage is a function of the complexity of the monitoring system (i.e. number of sensors used) and the interrogation interval selected. These intervals can vary from 3 min to 4 hr. The approximate numbers of days of unattended cassette data recording for the different interrogation intervals available in the field station recorder are given on the following page.

Interrogation Interval min	Recording Days per 90-m Cassette Tape, 32-Channel Field Station with 31 External Sensors
240	120
120	60
60	30
30	15
15	7
10	5
5	2
3	1

22. Operation. The field station contains a clock that produces a command signal at selectable intervals to activate the station. The cassette tape recorder (paragraphs 19-21) begins to step while the system electronics is going through an initial reset, thus generating an interrecord gap. The station then sequences through the data channels and converts the analog signals into digital data (paragraph 26). The analog output is converted to a digital serial pulse train. The serial data and the station clock (time) data are both sequentially recorded on the cassette tape for each recording period.

23. The control logic takes the data and sequences them into the following 12-bits-per-word data format:

SYNC	2^0	2^1	2^2	2^3	2^4	2^5	2^6	2^7	2^8	2^9	PTY

The first bit is always a logical "1" and is used as a sync bit. The next 10 bits are the binary representation of the data, with the least significant bit first. The last (twelfth) bit in the data record is parity.

24. The parity bit on the tape is quite useful in checking data. Checking for parity is a simple, rapid way of determining whether data have been recorded and reproduced properly. The number of bits of a data word plus the sync bit is totaled. If the total is even, a parity bit is added to make the total odd. If an error occurs in recording data, the error can be detected and the information flagged as being invalid. Parity-generating circuitry is built into the field station

electronics as a standard design feature.

Housekeeping boards

25. Station timer board. The station timer board contains a 139.776-kHz, crystal-controlled oscillator with a two-phased station clock; one phase controls the system interrogation interval, and the other contains an automatic shutdown feature. The interrogation circuitry allows the field station to be activated at user-selected time intervals. At present, there are 10 system interrogation intervals (3, 5, 10, 15, 20, 30, 40, 60, 120, and 240 min). The automatic shutdown feature limits the use of the station power supply in the event the normal sampling sequence fails. This shutdown occurs 15 sec after normal sequence failure.

26. A-D converter board. The A-D converter board receives analog information from the external sensors and, using a dual-slope integrating technique, converts the analog input voltage into a digital pulse train that is directly proportional to the input voltage. Excellent noise immunity is obtained with this technique over the period of integration. Each external sensor is connected to a channel of a multiplexer, and upon command, the multiplexer displays the sensor input for the channel selected. The number of pulses (counts) contained in the output pulse train is an exact function of the magnitude of the sensor input voltage. This pulse is then transferred to the counter board.

27. Counter board. The counter board counts and holds digital inputs from the A-D converter board. The output of the counter is then applied to a digital multiplexer, which converts the parallel sensor data into serial data.

28. Power regulator board. The power regulator board consists of the power control circuit and the switched (+5-V) regulator circuit. The function of the power regulator board is to switch the battery voltage to the regulator circuits upon command from the interrogation clock.

29. Cassette tape drive board. The cassette tape drive board contains the electronics for driving the station tape recorder. This board provides the voltage necessary to operate the recorder's stepper

motor (paragraph 22) and the takeup motor during each interrogation or sampling period.

Signal-conditioning boards

30. The 32-channel LEC field station has a unique channel-expansion feature, which allows the system to be configured for any number of data channels from 1 to 31, two channels at a time. (Channel 0 is normally used for counting the number of interrogations.) Channel expansion is accomplished by simply inserting any of four optional signal-conditioning printed circuit cards (i.e. boards) sequentially into the prewired card sockets and adding signal-conditioning power supply boards as required.

31. The four basic types of signal-conditioning boards used with the field station are: (a) time and site (T&S), (b) digital event accumulator (DEA), (c) thermistor conditioning amplifier (TCA), and (d) variable gain amplifier (VGA). The functions of these boards and that of the signal-conditioning power board are described below.

32. T&S board. This board allows reading and recording of a preselected 3-digit number, such as 033. The advantage of using a channel of "fixed" data is to provide a set of binary represented data (paragraph 23) in which the numbers are specified (i.e. known), thereby ensuring that the data information transfer logic is working properly. The coded number can also be a reference for the location of the station or other information such as site identification.

33. DEA board. The DEA board counts and accumulates digital data between interrogations and enters the data on the cassette tape during interrogation. The board contains a two-word counter, data control logic, two digital event accumulators, a 24-bit parallel-to-serial shift register, and multiplexer switches. The first digital event accumulator has a special feature that allows the accumulator to be used as a data record counter. A switch provides two operating modes. Switch position 1 is the normal mode, in which the counter accumulates external digital events and is reset by interrogation. The second mode is for record count, in which the counter is advanced one count each time an interrogation occurs. The accumulator can then be manually

reset by a push button at the beginning of a test (or data collection period), and counts of interrogations are accumulated and recorded from that time on.

34. TCA board. The function of the TCA board is to convert a thermistor or other varying resistance to a proportional voltage whose range is 0 to 1.0 V full-scale. For a thermistor temperature range of -40 to +60°C, an 0.01-V change equals 1°C. The circuitry operates over a resistance range of 5,000 to 16,000 ohms and contains a two-word counter, control logic, two amplifiers, and multiplexer switches.

35. VGA board. The function of the VGA board is to amplify low-level sensor input signals. It contains two high-stability d-c amplifiers, multiplexers, and a word counter. The amplifiers can accept input voltages ranging from 10 mV to 1.0 V full scale to handle a number of different types of sensors.

36. Signal-conditioning power board. This board converts the +12 V of power from the battery to +15 V for use with the analog circuits, A-D converter, and amplifiers. One signal-conditioning power board provides sufficient power for obtaining data with eight channels (*i.e. from eight sensors*). For a 31-sensor configuration, four signal-conditioning power boards are required.

Specifications

37. Specifications for the field station are summarized below.

a. Number of data channels: 32 (one channel for the counter and 31 channels for recording sensor data).

b. Sampling rate: 8 channels/sec.

c. Cassette tape size: 0.635 cm (1/4 in.).

d. Cassette tape length (one side): 86 m + (0 + 4 m); other tape lengths are also available.

e. Data recording density: 47.24 bits/cm (120 bits/in.).

f. Sampling or interrogation intervals: 3, 5, 10, 15, 20, 30, 40, 60, 120, 240 min.

g. Word length: 12 binary coded decimal (BCD) characters including sync and parity bits.

h. Power source: 4.5 amp-hr rechargeable battery (+12 V).

i. Cassette storage capacity: 200,000 bits (one side of tape).

j. Weight of 32-channel field station (without sensors and cables): 10.9 kg (24 lb).

k. Station electronics operating temperature range: -40 to +52°C.

l. Station container size and construction: 20- by 40- by 46-cm, sealed, fiberglass container.

PART III: SENSORS BEING USED WITH THE FIELD STATION

38. Sensors have been interfaced with the field station to provide measurements of the following environmental parameters:

- a. Air temperature
- b. Solar radiation
- c. Wind speed
- d. Wind direction
- e. Rainfall
- f. Evaporation
- g. Soil temperature
- h. Water level
- i. Water velocity
- j. pH of water
- k. Dissolved oxygen
- l. Water conductivity
- m. Water temperature
- n. Water transmissivity

Additional parameters that can be measured with sensors that are available for use with the field station are listed in Table 1. This section of the report describes the sensors listed above, their restricted output characteristics, and their maintenance and calibration requirements.

Air Temperature

39. Ambient air temperature is measured with a Lockheed Model S1081 sensor (Figure 5), which incorporates a thermolinear thermistor network as the sensing element. This network is a composite device consisting of resistors and thermistors configured to produce an output resistance that is linear with temperature.

40. The sensor resistance is characterized by the following equation:

$$R_t = k_1 t + k_2$$

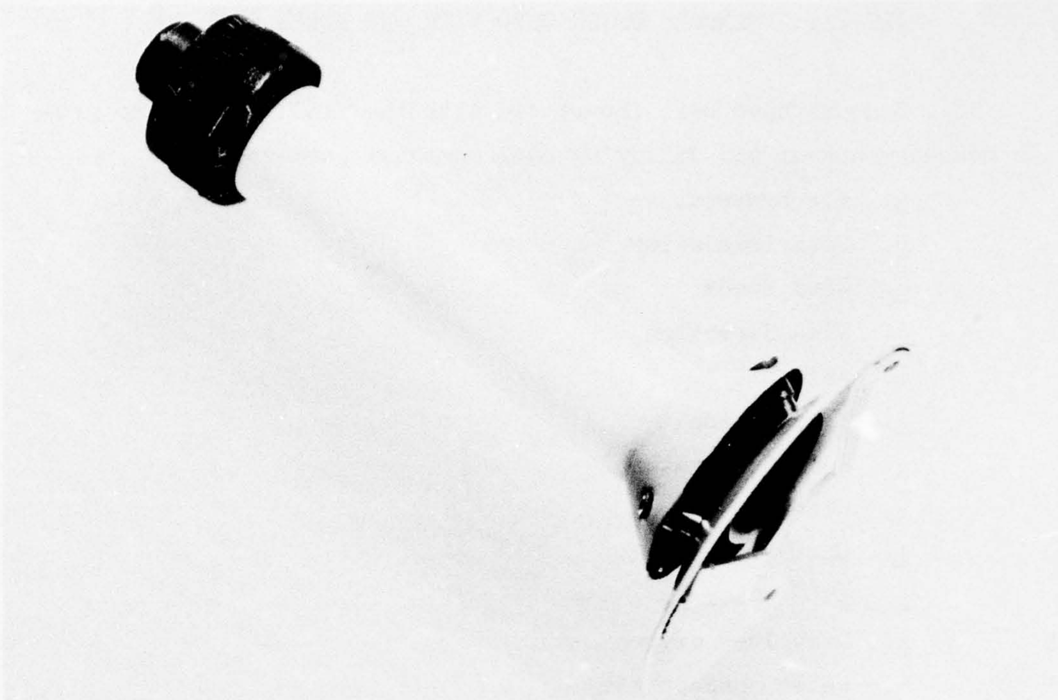

Figure 5. The LEC Model S1081 air-temperature sensor

where

R_t = total sensor resistance, ohms

k_1 = 127 ohms/°C

t = temperature, °C

k_2 = 12,176 ohms

41. The sensor enclosure is designed with a triple shield that eliminates the effects of both direct and reflected solar radiation upon the sensing element. A "chimney" design creates a smooth flow of the ambient air around the sensing element without forced aspiration.

42. All Model S1081 temperature sensors have almost identical characteristics and thus are interchangeable with almost no degradation of the accuracy at which temperature is being measured. Their characteristics are as follows:

a. Temperature range: -40 to +60°C.

b. Calibrated accuracy: ±0.15°C.

c. Sensitivity: 127 ohms/°C.

Signal conditioning

43. The air-temperature sensor was designed to interface with the standard TCA board (paragraph 34) and produces a linear output of 0-1.0 V over a temperature range of -40 to +60°C.

Maintenance

44. Because of inherent simplicity of the temperature sensor, little maintenance is required other than periodic checking of the housing to ensure unrestricted airflow around the sensing element.

Calibration

45. An air-temperature sensor is calibrated by comparing its recorded output, as read by the Lockheed 250 analyzer/translator or Model 260 data display (paragraphs 137 and 138), with a high-quality, mercury-filled, centigrade thermometer that has been checked against a precision thermometer certified by the National Bureau of Standards. Three points are normally sufficient to establish proper sensor calibration.

Solar Radiation

46. Solar radiation is measured by using two different pyranometers, a Matrix* Mark 1-G Sol-A-Meter and an Eppley** precision spectral pyranometer.

Matrix Sol-A-Meter

47. The Matrix Mark 1-G Sol-A-Meter (Figure 6) is a silicon photovoltaic cell pyranometer with a spectral response from 0.35 to 1.15 μm with a peak sensitivity at 0.85 μm. It is temperature compensated (-40 to +60°C) and generates a millivolt signal output (0-70 mV) that is proportional to the total incident radiation (0-140 mW/cm^2). The cell is mounted under a rugged Pyrex hemisphere for protection and takes less than 1 msec for 0-100 percent response.

48. The Sol-A-Meter can be used to measure (a) incident radiation

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* Matrix Inc., Mesa, Arizona.
** Eppley Laboratory, Inc., Newport, Rhode Island.

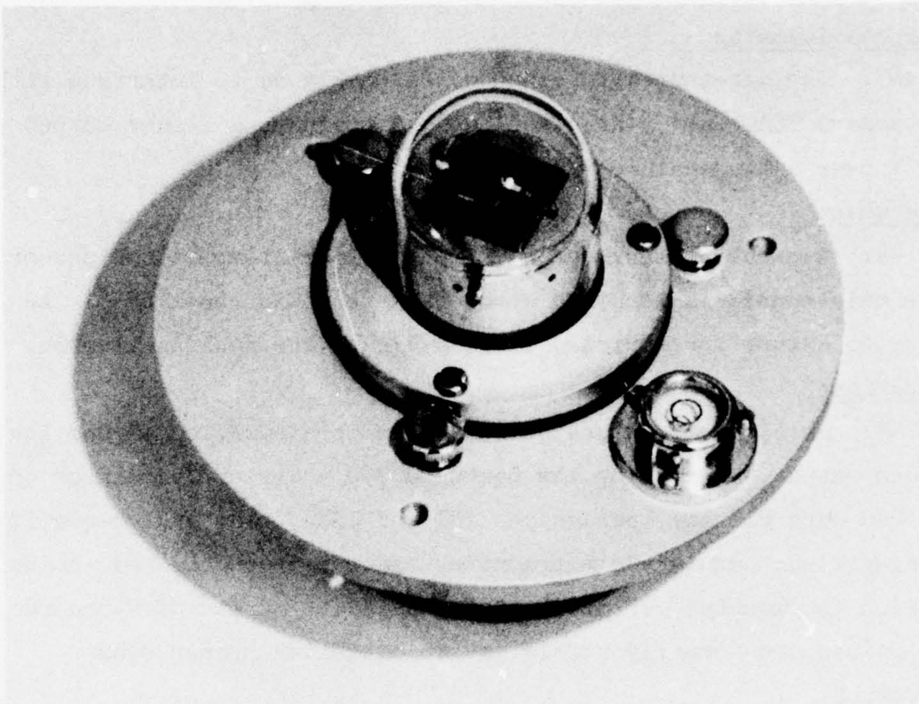

Figure 6. Matrix Mark 1-G Sol-A-Meter

over its entire bandwidth (i.e. 3.5-1.15 μm), (b) reflected radiation by inverting the sensor, and (c) radiation in a specific bandwidth by using special filters. Regardless of what radiation is being measured, it is imperative that the sensor be placed far enough from any obstructions that the sun never casts a shadow on it. Also, it is extremely important that the "bulls-eye" leveling device on the sensor housing be leveled prior to use.

49. The signal output of the sensor is related to solar radiation by the following equation:

$$R = 69.73(av + b)$$

where

R = radiation, mW/cm^2

a = the slope (≈ 0.02) of the calibration curve (Figure 7)

v = output of sensor, mV

b = the zero offset (≈ 0.04) which is dependent upon the individual sensor

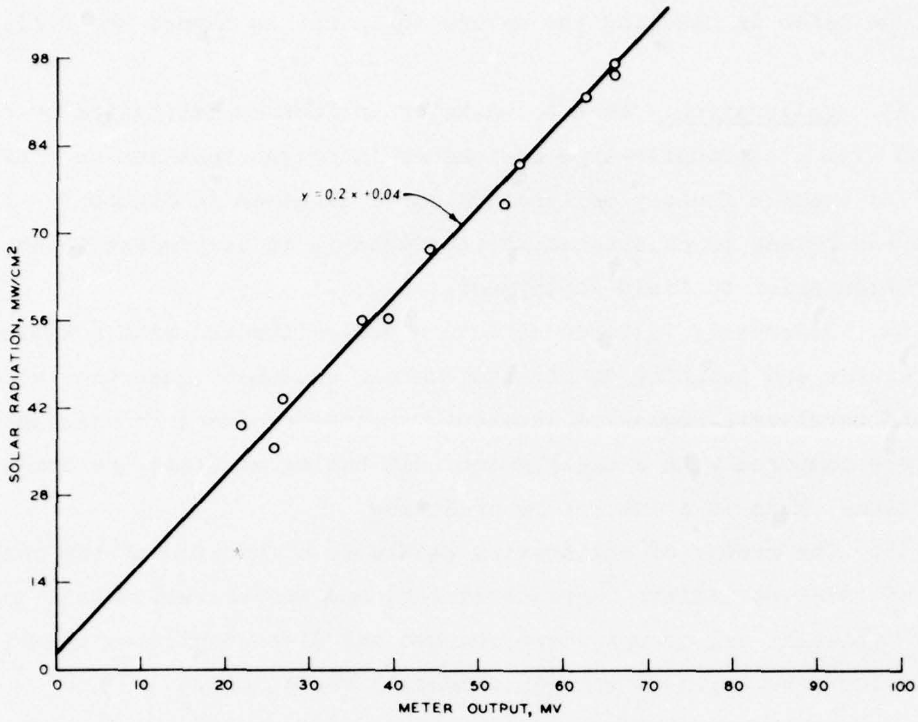

Figure 7. Typical calibration curve for Matrix 1-G Sol-A-Meter

50. Some characteristics of the Matrix Sol-A-Meter are as follows:

a. Range: 0-140 mW/cm^2.

b. Calibrated accuracy: ±5 percent.

c. Size: base diameter, 12.7 cm.

d. Weight: 680 g (1-1/2 lb).

51. Signal conditioning. Signal conditioning is achieved by means of the VGA board (paragraph 35), such that the entire sensor output range of 0-70 mV is usable, or under certain light conditions, much smaller portions of the range can be used. In any case, the output of the VGA board is 0-1.0 V.

52. Maintenance. Maintenance of the Sol-A-Meter requires periodic cleaning of the Pyrex dome with a lint-free cloth and inspection of the desiccant. Even though the unit is environmentally sealed, moisture can form underneath the Pyrex dome. The dome can be removed carefully on a dry day, allowing air to evaporate the moisture. The inside of the dome should not be wiped unless smears are visible. Care must

always be taken in handling the device so as not to damage the silicon cell.

53. Calibration. Each Sol-A-Meter is factory calibrated by comparison with a thermopile-type radiometer in bright sunshine on clear days. An example factory calibration curve is given in Figure 7. Even though the device is calibrated at the factory, it is prudent to check calibration prior to field deployment.

54. Discretely filtered detectors are calibrated with a known light source and scanning spectroradiometric equipment over the intensity and wavelength region of interest. Spectroradiometric sensing units are compared with a calibration unit having at least the same resolution. This is a laboratory procedure.

55. The number of calibration points is a function of the bandwidth of interest, filter characteristics, and spectroradiometric solution. Typically all abrupt slope changes and discontinuities should be covered for wavelength as well as intensity variations.

Eppley spectral pyranometer

56. The Eppley pyranometer (Figure 8) is a precision device using a circular multijunction Eppley thermopile that is extremely shock- and vibration-resistant. The sensing element is mounted in a chromed brass case supplied with a pair of removable, precision-ground, polished, concentric hemispheres of Schott optical glass, the inner of clear WG (white glass) 7 glass, and the outer of WG 7 or yellow GG (green glass) 14, orange OG (orange glass) 1, red RG (red glass) 2, or dark-red RG 8 filter glass. Also incorporated is a desiccant, which can readily be inspected. The instrument has a chromed brass stand with a white enameled guard disc. The clear WG 7 glass is transparent from a wavelength of about 0.285 to 2.8 μm. The centers of the lower sharp cutoff of the hemispherical filters are as follows: GG 14, approximately 0.5 μm; OG 1, 0.5 μm; RG 2, 0.63 μm; and RG 8, 0.7 μm. For solar ultraviolet measurements, hemispheres of quartz are used.

57. Characteristics of the Eppley pyranometer are given below.

a. Range: 0-280 mW/cm^2.

b. Calibrated accuracy: ±0.5 percent.

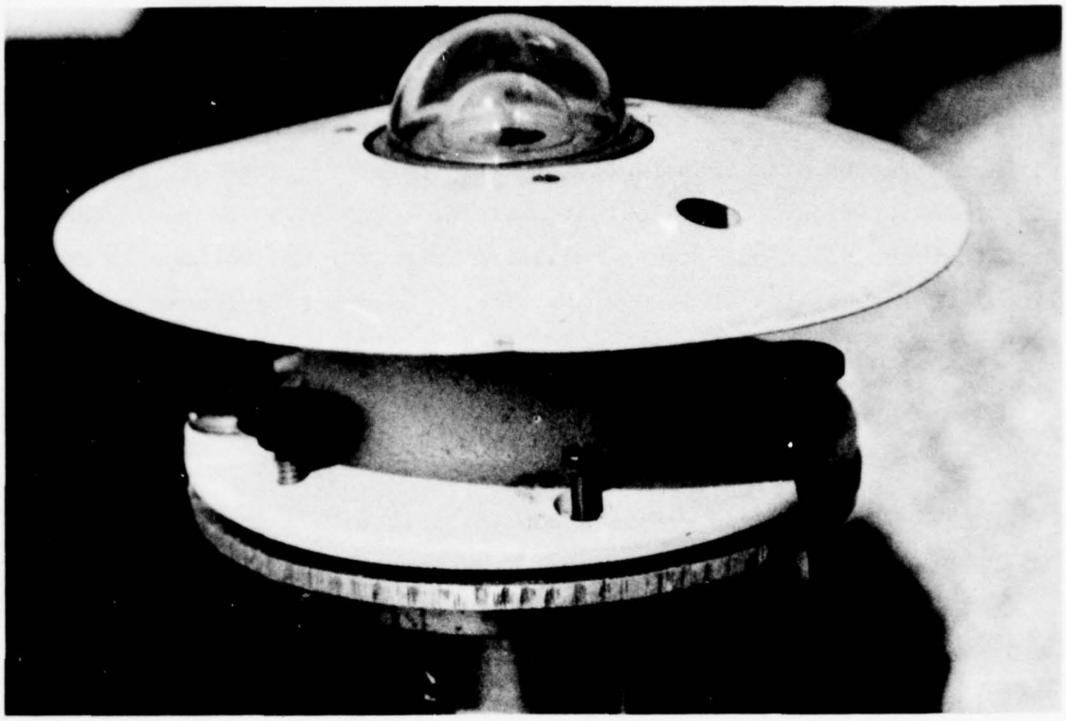

Figure 8. Eppley Laboratory spectral pyranometer

c. Sensitivity: 0.1 mV per mW/cm^2 (approximate).

d. Temperature compensation (standard): -20 to +40°C.

e. Temperature compensation (optional): -70 to +50°C.

f. Mechanical vibration: 20 g's produce no damage to the device.

58. Signal conditioning. Signal conditioning for the Eppley pyranometer is accomplished with the VGA board (paragraph 35), and for most circumstances, the calibration is such that a sensor output of 0-35 mV produces 0-1.0 V recorded on the cassette tape.

59. Maintenance. For the proper maintenance of the Eppley pyranometer, as often as possible the outer hemisphere should be wiped very gently with a clean lint-free cloth, so as not to scratch the dome. Ice, frost, or snow is normally removed with warmed cloths, if possible. Any moisture that collects on the inside of the outer hemisphere can be eliminated by removing the hemisphere and allowing the moisture to evaporate. The inner surface should not be wiped unless

smears are visible. The desiccant in the housing should be periodically inspected and replaced if it appears pinkish or white in color.

60. Calibration. Each Eppley spectral pyranometer is furnished with calibration data (constant), and the sensor requires little, if any, recalibration. The calculation of the constant is based on the fact that the relation between radiation intensity and voltage is rectilinear to intensities of 1400 W/m^2. The pyranometer is linear to within ± 0.5 percent of this intensity.

Wind Speed

61. Wind speed is measured continuously with a Climet* Model 011-2B wind-speed sensor (Figure 9), an accurate, durable, 3-cup-type, 2- to 161-km/hr anemometer. As the anemometer rotates, it actuates a sealed magnetic reed switch by means of a magnet attached to the sensor shaft. The output signal is a series of contact closures at a frequency proportional to wind speed. Reliability is ensured by incorporation of rugged materials, namely, Lexan anemometer cups, a stainless steel sensor shaft, Teflon-sealed stainless steel bearings, cast and machined anodized aluminum housing, etc., and by careful selection of seals and weatherproof connectors.

62. The detailed characteristics of the wind-speed sensor are as follows:

a. Range: 2-161 km/hr (1.25-100 mph).

b. Calibrated accuracy: ± 2 percent or 0.40 km/hr, whichever is greater.

c. Output: 2 switch closures per revolution.

Signal conditioning

63. Signal conditioning is accomplished with the DEA board (paragraph 33), which counts the number of switch closures received during the interrogation interval and transfers the total accumulation of counts to the cassette tape. Later, appropriate software is used to

* Climet Instruments, Sunnyvale, California.

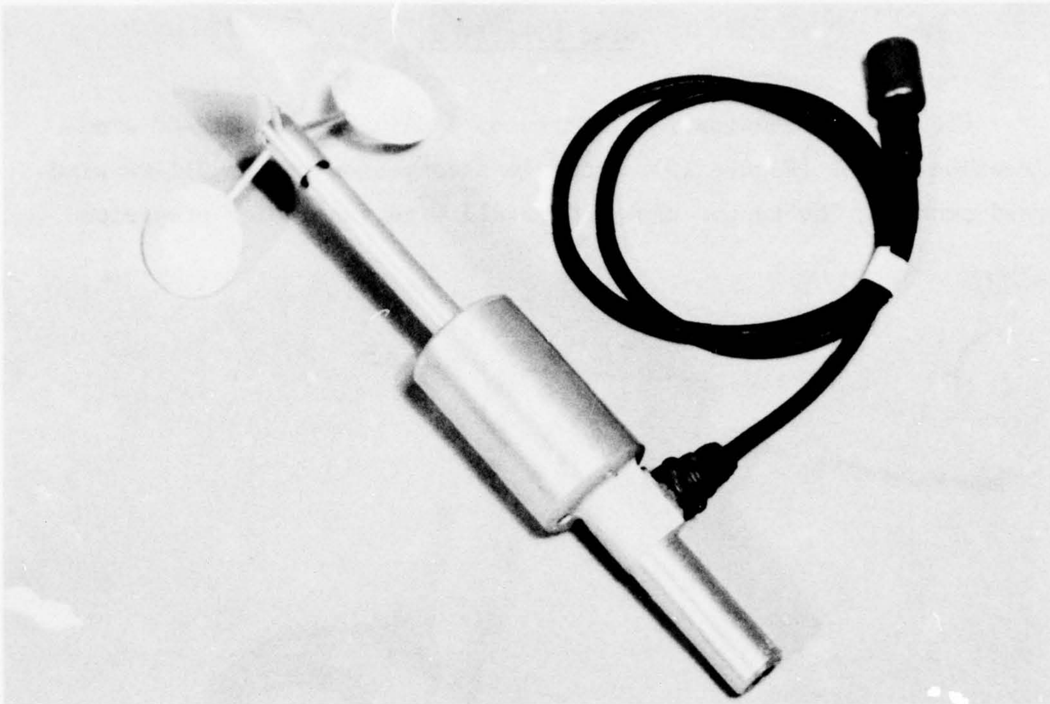

Figure 9. Climet Instruments Model 011-2B wind-speed sensor

calculate the average wind speed for the preselected interrogation period.

Maintenance

64. Periodic maintenance of the sensor is required to ensure continued accurate wind-speed measurements. Preventive maintenance includes lubrication of the "O-ring" seal to the sensor housing approximately every 6 months and replacing the bearings every 12 months, unless extreme climatic conditions dictate replacement more frequently.

Calibration

65. There is no convenient method of precisely checking calibration of the wind-speed sensor in the field other than to ensure that it produces the correct number of counts for every revolution as read by the LEC Model 250-analyzer/translator or Model 260 data display (paragraphs 137 and 138). The laboratory procedure is to correlate the number of revolutions of the sensor with wind speed as measured by another accepted instrument.

Wind Direction

66. Wind direction is measured by a Climet Model 012-2B wind-direction sensor (Figure 10), which is a companion to the 011-2B wind-speed sensor. The sensor uses an airfoil wind vane and a precision

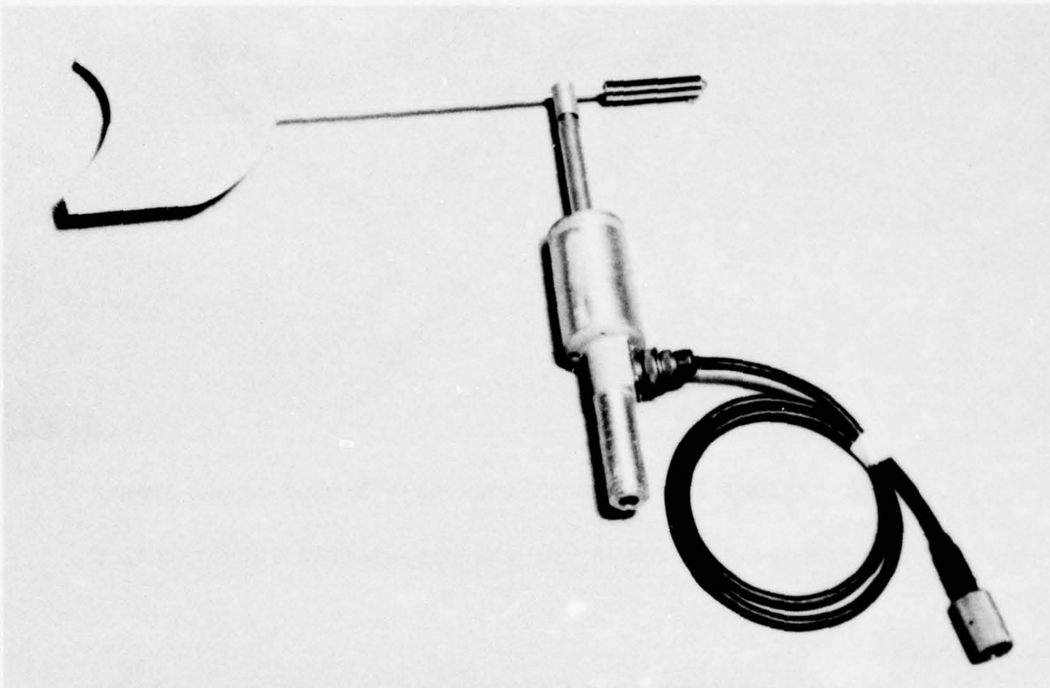

Figure 10. Climet Instruments Model 012-2B wind-direction sensor

potentiometer assembly to deliver a resistance analogous to the azimuth bearing of the wind.

67. Physically, the wind-direction sensor is similar to the wind-speed sensor in that it uses the same rugged materials and seals.

68. The detailed characteristics of the wind-direction sensor are listed below.

a. Mechanical azimuth range: 0-360 deg.

b. Electrical azimuth range: 0-354 + 2 deg.

c. Calibrated accuracy: ±5 deg.

d. Resolution: 0.5 deg.

e. Minimum wind speed for direction measurement: 1.6 km/hr (1 mph).

Signal conditioning

69. A TCA board (paragraph 34) is used to condition the signal delivered by the wind-direction sensor. Electrical resistances of 15,000 and 5,000 ohms correspond to azimuths of 0 and 355 deg, respectively. The sensor also contains what is referred to as a "dead band" from which no output voltage is delivered from the sensor; this occurs for wind azimuths of 355 to 359 deg. Since the data as described by the dead band are different from the normal data, the software (paragraphs 140-143) converts the dead-band data to an average azimuth reading of 357 deg.

Maintenance

70. Periodic maintenance of the sensor consists of lubricating the "O-ring" seal approximately every 90 days and checking the sensor components for signs of wear and corrosion. At 12-month intervals, the sensor bearings should be replaced unless extreme use dictates replacement more frequently.

Calibration

71. A wind-direction sensor is calibrated by precisely orienting the wind vane to magnetic north and reading the corresponding count on the data display (paragraphs 137 and 138). A 180-deg rotation of the vane will then provide a second calibration point.

Rainfall

72. Rainfall is measured continually with a Weather Measure* Model P-501 rain gage (Figure 11). The rain gage has an 20.3-cm-diam orifice protected by a heavy brass ring and uses a tipping-bucket mechanism coupled to a mercury switch to produce an output. All internal parts are aluminum, chrome-plated brass, or stainless steel. The tipping-bucket mechanism uses balanced polyethylene buckets suspended on stainless steel pivots.

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* Weather Measure Corporation, Sacramento, California.

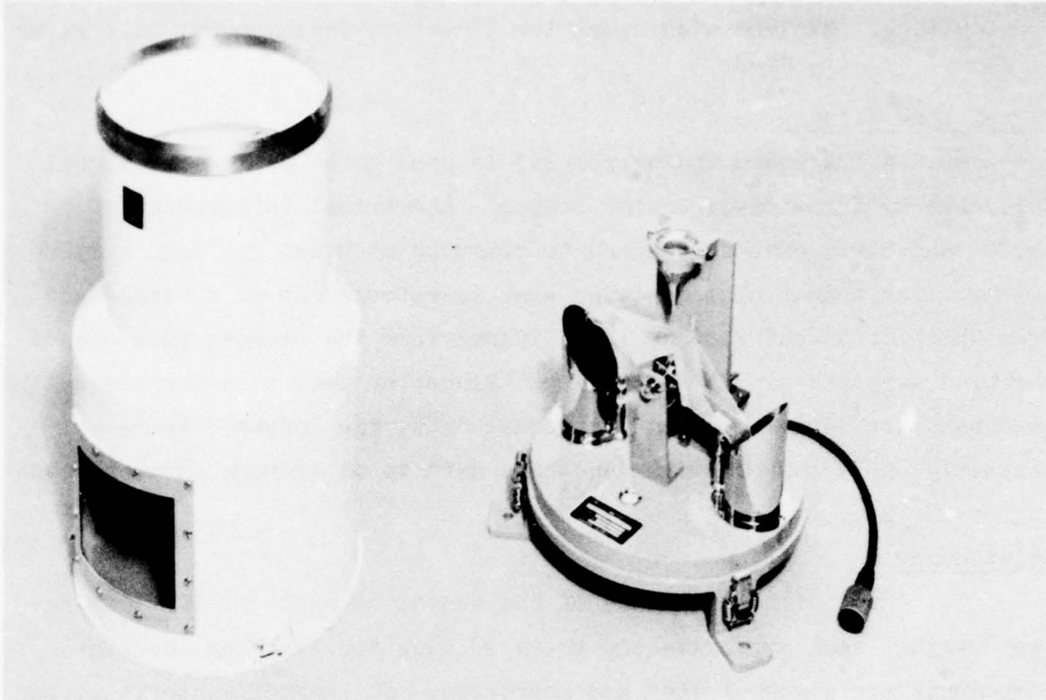

Figure 11. Components of Weather Measure Model P-501 rain gage showing tipping-bucket mechanism

73. As rainfall enters the orifice, it is drained into the gage's interior into one of the two buckets in the tipping mechanism. When one bucket is full, the weight of the water causes it to tip and the second bucket swings into place beneath the entry funnel. As each bucket tips, the water drains out through the base of the gage where it can be accumulated and analyzed, if desired. The tipping action causes a mercury switch, beneath the tipping-bucket mechanism, to close momentarily. The gage is calibrated such that one switch closure is produced for each 0.0254 cm of rainfall.

Signal conditioning

74. Signal conditioning is accomplished with a standard DEA board (paragraph 33), which counts the number of switch closures received during the interrogation interval and transfers the total accumulation of counts to the cassette tape. Later, appropriate software is used to calculate the total rainfall for the interrogation interval.

Maintenance

75. The only routine maintenance required is cleaning and occasionally applying a light silicon oil to the pivots of the buckets and to the mercury switch. The snaps on the outside of the gage require coating periodically with a good rust-preventative spray.

Calibration

76. Rain-gage calibration is accomplished by introducing into the gage orifice an exact volume of water ($1.6206\ cm^3$), or multiples thereof, equal to the amount required to tip one bucket of the tipping-bucket mechanism as originally calibrated by the factory. The number of counts should equal the number of multiples of the unit quantity of water introduced.

Evaporation

77. Evaporation of water from a vessel of known surface area and height above ground is measured with a Universal Engineered Systems* Model T-66 position (water-level) sensor (Figure 12) in conjunction with a Weather Measure Corporation E816 evaporation pan and E814A still well.

78. As installed in the field, the water-level sensor (T-66) is mounted on a horizontal platform directly above the evaporation pan (Figure 13). A polymer float rides on the water surface and is connected by a stainless steel tape to the tape wheel and gearbox, which, in turn, positions a precision potentiometer as the water evaporates. Optimum sensitivity is provided by antibacklash gears and precision stainless steel bearings. The T-66 is contained in an all-weather cast aluminum enclosure and has a tripod mounting for leveling. The function of the E814A still well is to provide a plane surface free of ripple upon which the float can ride.

79. Characteristics of the T-66 water-level sensor are as follows:

a. Standard water-level elevations: 0.76, 1.5, 3, 6, 9, 12, 15, 21 m, full-scale; others are also available. (For evaporation, only the first or second elevations are

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* Universal Engineered Systems, Pleasanton, California.

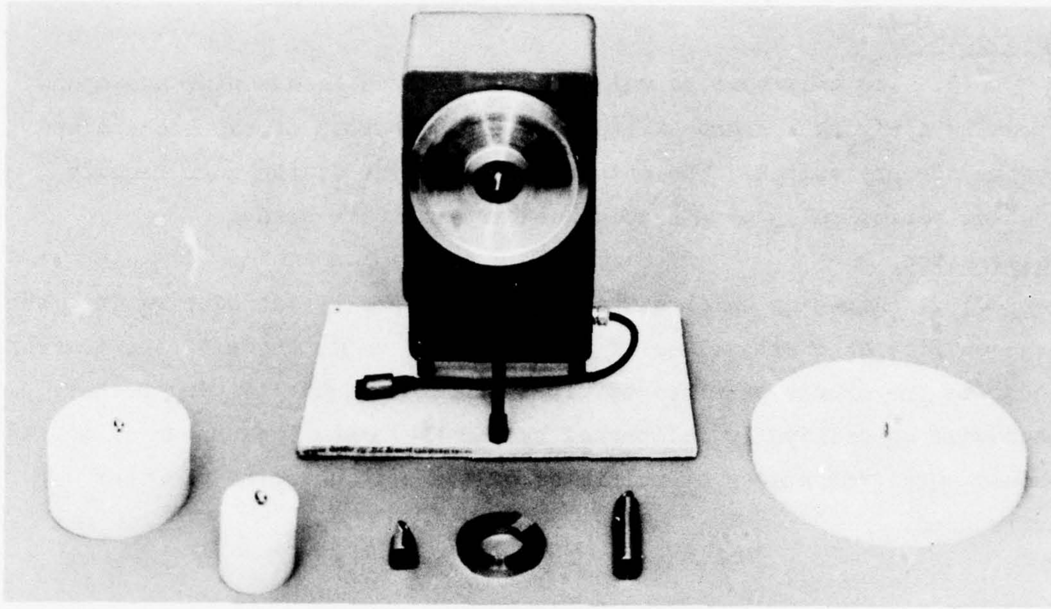

Figure 12. Universal Engineered Systems Model T-66 water-level sensor

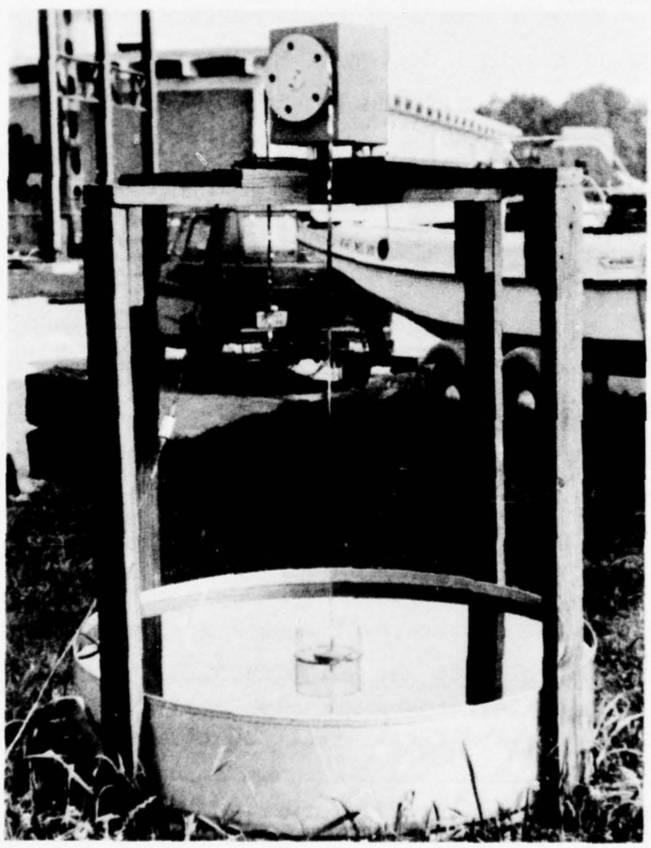

Figure 13. Components for measuring water evaporation consist of a Universal Engineered Systems Model T-66 water-level sensor and Weather Measure Corporation E816 evaporation pan and E814A still well

used.) Rotary input: 0.5, 1, 1.5, 2.5, 5, 10, 20, 25 turns, full-scale.

b. Calibrated accuracy: 0.2 percent (standard); 1.5 percent (optional).

c. Sensitivity: 0.05 percent.

d. Input: 0-180 deg to 0-25 revolutions, full-range; float tape, counterweight; gears.

e. Resistance: Potentiometer: 10,000 to 15,000 ohms.

f. Floats: Extruded polymer; standard sizes 10.2-, 15.2-, 20.3-, 25.4-, and 30.5-cm diam.

g. Standard tape wheel: 60.96-cm circumference; aluminum with stainless steel indexing pins spaced 15.2 cm apart.

h. Dimensions: 23 cm wide by 46 cm high by 23 cm deep.

i. Weight: Approximately 9.07 kg (20 lb).

Signal conditioning

80. Signal conditioning is accomplished with a standard TCA board (paragraph 34) with the T-66 linear resistance range of 15,000 to 10,000 ohms, corresponding to a range of 100 to 900 mV recorded on the cassette tape.

Maintenance

81. Periodic maintenance includes ensuring that the stainless steel tape is properly seated on the T-66 tape wheel and that the float is riding freely on the water surface. The evaporation pan should be inspected for water level during long dry periods or when installed in dry climates. Also, a resupply of water to the evaporation pan may be necessary for certain types of monitoring problems.

Calibration

82. The evaporation-sensor calibration is accomplished by artificially changing the evaporation pan water level by any unit amount and observing a unit change on the data display (paragraphs 137 and 138). This procedure may be repeated for as many different elevations as desired.

Soil Temperature

83. Soil temperature is measured with a Lockheed Model S1071

soil-temperature sensor (Figure 14), which has a thermilinear network as the sensing element. This network is identical in makeup and

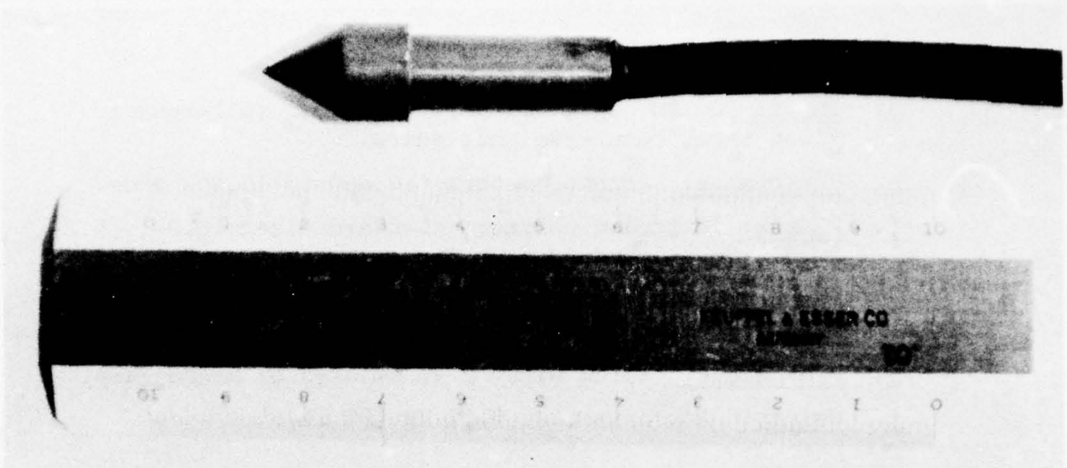

Figure 14. Lockheed Model S1071 soil- (and water-) temperature sensor

electrical characteristics to the one used for measuring air temperature (paragraphs 39-42); the signal conditioning is also the same (paragraph 43).

84. The sensor is potted in the nose of an aluminum, bullet-shaped, conductive housing such that it can be pressed into the soil at the depth desired. The thermolinear network and wiring are potted in a moisture-proof housing. The time required for the sensor, in its housing, to indicate 63 percent of a change in temperature in most soils is approximately 20 sec.

Maintenance

85. After each use, the sensor should be cleaned with a wet towel or cloth; no other routine maintenance is required.

Calibration

86. A soil-temperature sensor is calibrated in the same manner as is the air-temperature sensor (paragraph 45).

Water Level (Stage)

87. Tidal and other water-stage variations are measured

automatically with a Universal Engineered Systems Model T-66 water-level (position) sensor (Figure 12 and paragraphs 77-79). This sensitive, accurate, and reliable device converts linear or rotary motion into an electrical analog or digital measurement.

88. As installed in the field, the water-level sensor is mounted (and leveled) on a horizontal platform above the water body. A polymer float rides on the water surface within a deployed still well and is connected by a stainless steel tape to the tape wheel and gearbox of the sensor. A weight on the other end of the tape keeps the tape seated on the wheel. As the water level rises and falls, the polymer float is displaced; the displacement is recorded by a precision potentiometer connected to the tape wheel and gearbox.

89. The function of the still well is to provide a plane surface free of ripple and debris upon which the float can ride.

Signal conditioning

90. Signal conditioning is accomplished with a TCA board (paragraph 34) with the sensor linear output resistance range of 15,000 to 10,000 ohms, corresponding to a range of 100 to 900 mV recorded on the magnetic tape.

Maintenance

91. Periodic maintenance involves cleaning debris away from the still well and ensuring that the float is riding smoothly on the water surface and that the stainless steel tape is properly seated on the tape wheel of the sensor.

Calibration

92. Water-level sensor calibration is accomplished by simulating a unit change in water stage and observing a unit change on the data display (paragraphs 137 and 138). This procedure can be repeated at different water stages as desired.

Water Velocity

93. Water velocity is measured continuously with a Kahl Scientific

Model 232WA240* low-friction, contact-type, water-velocity sensor (Figure 15). This sensor is well suited for determination of currents in

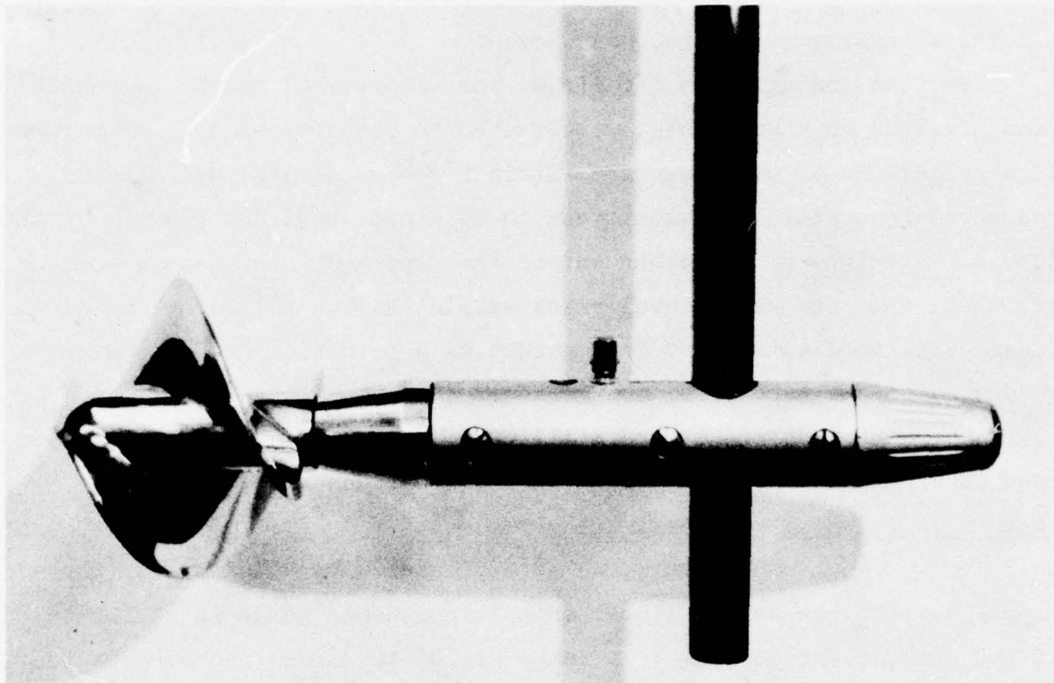

Figure 15. Kahl Scientific Instruments Model 232WA240 water-velocity sensor

open or restricted waterways. It provides reliable data for currents up to 10 m/sec; it is extremely sensitive to slow currents and begins indicating at 0.05 m/sec. The water can be clear or even somewhat turbid since the sensor's bearings are well shielded.

94. The current-velocity sensor has a fixed, waterproof main body that is machined from a solid brass bar. A contoured, highly polished, corrosion-resistant-alloy, lightweight propeller (which may be provided with a special coating for additional protection in saline waters) is rotated by the water current. The movement of the propeller is quite smooth because of special design features, such as a stainless steel propeller shaft and ball bearings to ensure proper operation under

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* Kahl Scientific Instrument Corporation, El Cajon (San Diego), California.

different environmental conditions. With every half turn of the propeller, its magnet actuates a switch encapsulated in the sensor body. The number of contacts per unit time is counted, and this value is converted to the number of turns of the propeller for the unit time. In practice, the number of propeller turns per minute is calculated, and from this, the water velocity is derived with the following equation:

$$V = an + bn^2 + c$$

where

- V = water velocity per unit time (usually portrayed in m/sec)
- a = pitch of the propeller, m
- n = number of turns of the propeller per unit time
- b,c = constants depending on the water friction on the propeller vanes and on the bearing friction

The friction terms are negligible for the Kahl sensors for velocities above 1 m/sec because of the precision used in fabrication as well as the special surface of the propeller; in such cases, the equation is a direct proportion:

$$V = an$$

Signal conditioning

95. Signal conditioning is handled by a DEA board (paragraph 33). The total number of switch closures occurring during each interrogation interval is counted and recorded on the cassette tape. Appropriate software (paragraphs 140-143) later converts the sensor data to the current velocity in metres per second.

Maintenance

96. This sensor requires cleaning and lubrication approximately once a month for best results.

Calibration

97. A calibration curve is furnished with each unit, which gives the number of turns of the propeller as the abscissa and water

velocity in metres per second as the ordinate (Figure 16). There is no convenient means of precisely checking the water-velocity sensor

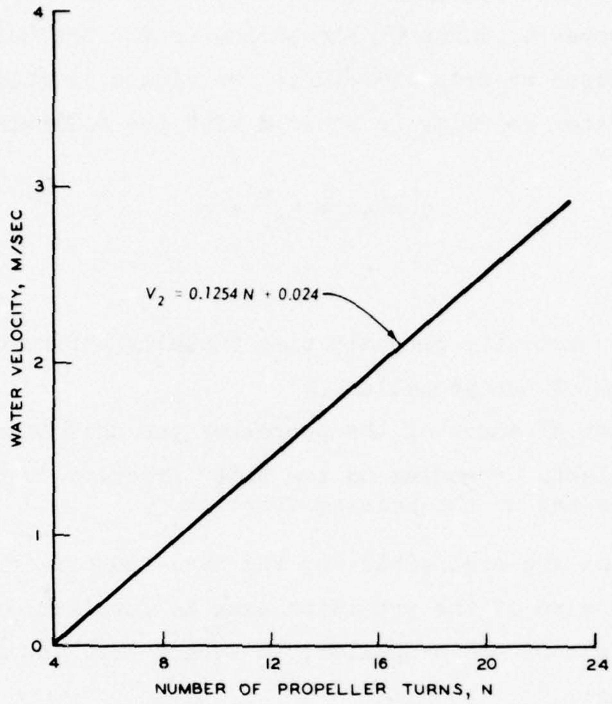

Figure 16. Calibration curve for Kahl Scientific Instruments Model 232WA240 water-velocity sensor

calibration in the field other than to observe that the sensor provides two output pulses per revolution of the propeller as read on the data display (paragraphs 137 and 138). For proper check of this calibration, several revolutions (≈100) of the propeller should be made, and the actual number of output pulses (counts) compared with the manufacturer's stated value. The laboratory procedure for sensor calibration is to correlate the number of propeller turns with water velocity measured by another accepted sensor.

Concentration of Hydrogen Ions (pH)

98. The negative logarithm of the hydrogen ion concentration is expressed as "pH" in gram-ions per litre. The pH scale varies from 0

to 14 and is based on the ionization of pure water. It is measured by sensing the potential difference between a reference electrode and a glass pH electrode. The magnitude of this potential difference, or signal, is 59.2 mV per unit of pH at 25°C; at pH 7 (neither acidic nor basic), the signal is 0 to ±40 mV, the actual value depending on the individual characteristics of the particular glass electrode used. For accuracy, all pH measuring systems must be temperature compensated; this is accomplished by a temperature-sensitive resistor or thermistor included in the pH amplifier circuit.

99. The two Martek Instruments* pH units used by the WES are characterized below.

	Mark II	Mark V
Range, pH	0-12	0-12
Calibrated accuracy, pH	±0.1	±0.03
Resolution, pH	0.01	0.01
Operating temperature range, °C	0-50	0-50
Output, mV	0-500	0-1000

Signal conditioning

100. Signal conditioning for either of the two units is accomplished with a standard VGA board (paragraph 35) set up so that its output is 0-1.0 V recorded on the cassette tape.

Maintenance

101. The bulb of the pH electrode and the tip of the reference electrode must be kept free of deposits. It is suggested that an intermittent stream of water be used to clean the electrodes after each use and once a week during continuous on-stream use. They may also be rubbed carefully with tissue. If necessary, hard-water deposits can be

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* The Mark II and Mark V sensor packages (Figures 17-19) also contain sensors for dissolved oxygen, conductivity, and water temperature and are all similar in resolution and accuracy; differences are primarily in size and configuration of the sensing elements, display meters, and signal-conditioning circuits.

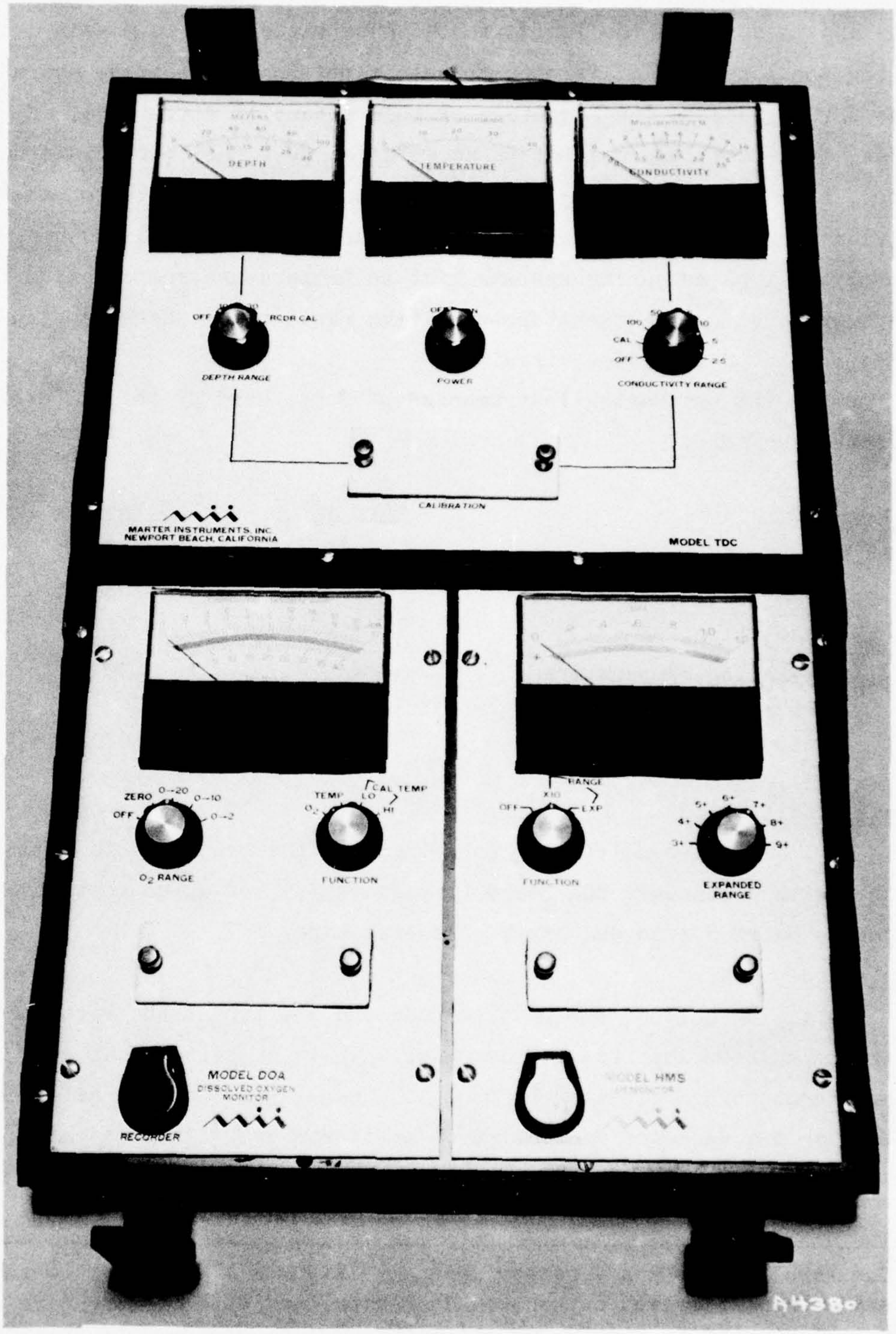

Figure 17. Martek Instruments Mark II water-quality display meter

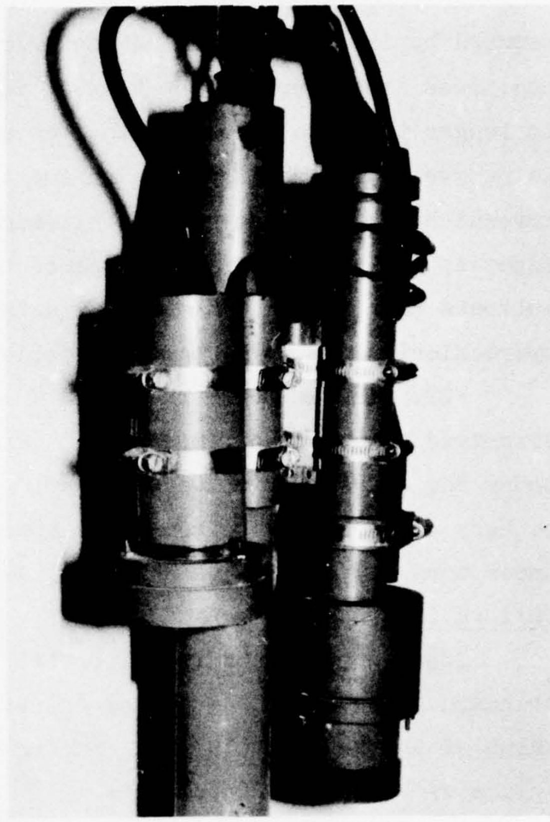

Figure 18. Martek Instruments Mark II water-quality sensor package

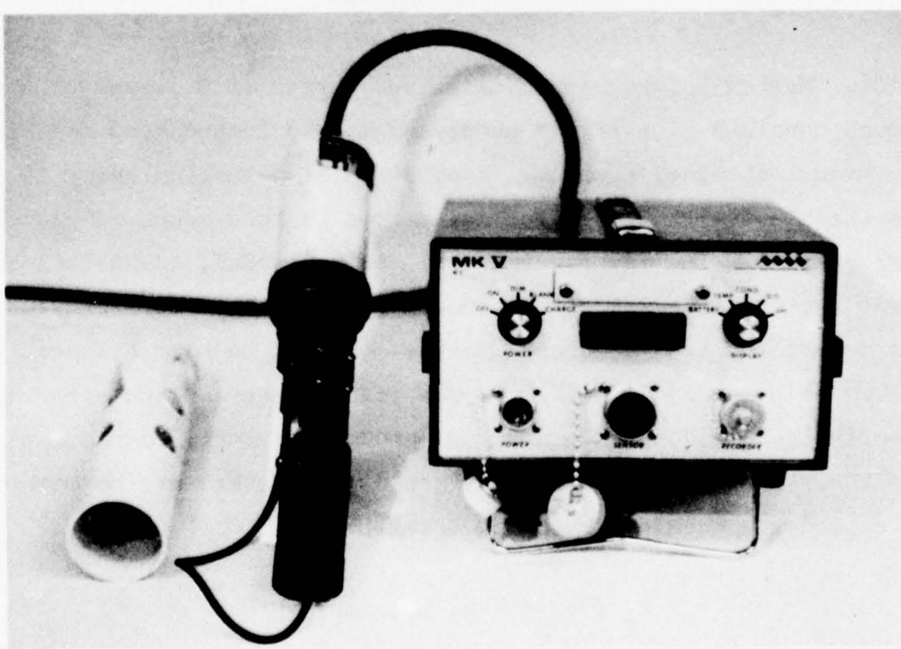

Figure 19. Martek Instruments Mark V water-quality sensor package

removed by immersion in diluted nitric acid, which will not damage the stainless steel probe. The time of immersion in nitric acid should be no longer than that required to loosen the deposits. Thorough rinsing to remove all traces of acid and soaking of the sensor in tap water for several hours are recommended following the acid treatment. Organic deposits are removed with a 70 percent ethyl alcohol solution or other solvents as required. Thorough rinsing and soaking in 0.1 normal hydrochloric acid is recommended following solvent treatments.

102. The Martek Mark II and V sensor packages (pH, conductivity, dissolved oxygen, and temperature) also require 12-V DC of external power for operation. Power supply is provided by the use of a wet-cell battery which has to be recharged approximately every 10 to 12 days under normal operating conditions (temperature above 10°C).

Calibration

103. A pH sensor is calibrated by immersing it in a beaker of standard pH buffer solution and comparing its output with the known value of the buffer solution. Buffer solutions used have nominal values of 4, 7, and 10 pH units.

Dissolved Oxygen

104. Martek polarographic dissolved oxygen (D.O.) sensors are used; each consists of a silver anode and a gold cathode enclosed in a PVC (polyvinylchloride) housing. A solution of potassium chloride is used as the electrolyte. A membrane, permeable to oxygen, is placed over the cathode. The membrane material is a special, tough Teflon, which has the characteristic ultrasmooth surface that helps prevent foreign materials, such as sludge, slime, grease, and marine organisms, from clinging to it. Aside from diffusing oxygen and other gases, it effectively shields the cathode and anode from contamination, prolonging their service life. When oxygen diffuses through the membrane to the cathode, a chemical reaction takes place:

$$O_2 + 2H_2O + 4e \longrightarrow 4OH$$

The related reaction at the silver anode in the electrolyte chamber is

$$4Ag + 4Cl \longrightarrow 4AgCl + 4e$$

A voltage applied across the two electrodes results in a current flow that is proportional to the partial pressure of oxygen at the probe tip, and the sensor produces an output signal as long as the electrolyte is exposed to oxygen. A pressure-equalizing diaphragm, on the side of the probe housing, flexes as necessary to provide pressure equalization across the Teflon membrane (in between the water sample and the electrolyte chamber), which is necessary when a closed electrolyte chamber is operated to and from water depths up to 100 m.

105. The two sensor packages (Martek Mark II and V as shown in Figures 17-19) are primarily intended for use in natural water bodies. The Mark II provides fast response to changes in D.O. level because of the use of a special stirrer mechanism and a very thin, rapidly responding membrane. A similar fast response is obtained with the Mark V by use of a special scraper, which is actually more effective in preventing contamination of the probe than is the stirrer.

106. A separate underwater temperature probe supplied with the Martek units is used to measure water temperature for the primary purpose of calibrating oxygen partial pressure values (as sensed by the D.O. probe) in terms of milligrams per litre. The temperature probe uses a factory-calibrated and aged disc-type thermistor with a time constant of approximately 10 sec as the sensing element. It forms part of an automatic temperature-compensation circuit, which corrects D.O. readings for both temperature effects on the oxygen probe membrane permeability and variation in oxygen solubility in natural waters as a function of temperature.

107. The two Martek D.O. sensors are compared below.

	Mark II	Mark V
Range, mg/l	0-2,0-10,0-20	0-20
Calibrated accuracy, mg/l	±1.0% of full scale	±0.05

(Continued)

	Mark II	Mark V
Resolution, mg/l	0.05	0.01
Operating range, °C	0 to +40	-30 to +70
Output, mV	0-500	0-1000

Signal conditioning

108. Signal conditioning of the two Martek D.O. sensors is handled by a VGA board (paragraph 35) set up so that it produces a 0- to 1.0-V output for 0- to full-scale input from the D.O. sensor.

Maintenance

109. The D.O. probes are constructed for long life with minimal maintenance. The electrolyte requires replenishment once every six months; the membrane does not have to be removed in the process of replenishing the electrolyte. Membranes normally require replacement no more often than twice a year; however, unusual chemical exposure or accidental physical damage can require more frequent replacements.

Calibration

110. A D.O. sensor is calibrated by immersing it in a beaker of air-saturated water and comparing its output with that obtained by a laboratory analysis of the water. The water is stirred or made to flow with sufficient velocity such that any increase in flow (or stirring) will not cause a change in the sensor output. The analysis is made in accordance with the Alsterbery modification of the Winkler method of D.O. determination. The water must be free of interfering substances; therefore, the use of deionized water is recommended. Care must be taken to allow adequate time in each test for the sensor to reach equilibrium.

111. The sensor is calibrated at three points: (a) preferably the zero level, (b) approximately one third of full scale, and (c) approximately two thirds of full scale. The zero level is obtained by adding a few crystals of cobalt chloride ($CoCl_2$) to a beaker of saturated sodium sulfite (NA_2SO_3) solution. Various concentrations of oxygen in air-saturated water can be obtained by changing the water temperature.

Water Conductivity

112. Electrolytic conductivity of solutions is a nonspecific measurement of the ions in a solution. The values obtained are a function of the number of ions, their electrical charge, and their rate of movement, which is also a function of temperature and the nature of the ion. Moreover, the magnitude of the temperature effects is different for the different ions and changes with concentration. Finally, it should be pointed out that the conductivity is not a linear function of the number of ions in the solution. For example, the use of electrical conductivity to obtain the exact concentration of salts in solution is restricted to solutions of known compositions such as seawater. When seawater is diluted by fresh water such as in an estuary, errors caused by changes in salt composition and dilution will result in less than accurate results. The use of conductivity data in very dilute solutions, as in fresh water to obtain concentration of dissolved salts, is an estimate at best. This measurement is based on a variation of Ohm's law:

$$\text{Conductance in mmhos} = \frac{\text{current}}{\text{voltage}}$$

Thus, if the voltage drop across two electrodes is kept constant, conductance is directly proportional to the current through the cell. This is the principle employed in the Mark II and Mark V packages.

113. The conductivity-measuring circuit in the Mark II and Mark V units consists of a very closely regulated 1000-Hz sine wave generator, which feeds its output (0.5 V) to the conductivity cell. The current passing through the cell is then fed to a current-to-voltage converter, where it is changed to an a-c voltage proportional to conductance. This a-c voltage is then converted to a pulsating d-c voltage by a phase detector, and the resulting DC can be read on a display meter supplied with the Mark II and Mark V and, by suitable signal conditioning, simultaneously output to the field station. Since the phase detector is sensitive only to that part of the signal that is in phase with the applied voltage, the overall circuit sees only the

cell resistance, not the cable capacitance, which would cause large errors. The conductivity cell has large nickel electrodes, which are coated with platinum black to increase the surface area, reducing resistive effects at the electrode surfaces.

114. Characteristics of the two Martek conductivity sensors are listed below.

	Mark II	Mark V
Range, mmhos/cm	0-100, 50, 25, 10, 5, 2.5	0-1000 or 0-100
Calibrated accuracy	2% of full scale	±5.0 or ±0.5 mmhos/cm
Resolution	0.1% of full scale	1.0 or 0.1 mmhos/cm

Signal conditioning

115. Signal conditioning for the two conductivity units is accomplished with a VGA board (paragraph 35) whose gain is set to produce a recorded output of 0-1.0 V analogous to 0- to full-scale sensor output.

Maintenance

116. Generally, the conductivity sensor is not responsive to deposit accumulation. However, an obstruction in the protective cylinder that surrounds the conductivity cell will prevent the free flow of water and may cause slow response. Also, the accuracy will be affected by the presence of deposits in the cylinder because the cell constant, a function of the physical dimensions of the cell, will be changed if the bore is narrowed. Any of the following methods can be used to clean the cylinder as required:

a. A high-speed stream of water can be directed through the cylinder.

b. A large obstruction can be pushed from the cylinder with a thin stick of wood. Metal or anything sharp that will scratch the cylinder, thus changing the dimensions, should not be used.

c. Diluted nitric acid, up to 20 percent concentration, can be used.

d. Sodium hydroxide (lye) or potassium hydroxide, any concentration needed, can be used.

e. A soft-bristle brush (not metallic, nylon, or other abrasive bristle) and detergent can be used.

f. *Oil can be removed as in method e or by using naphtha.* Other solvents may damage the plastic.

Calibration

117. The conductivity sensor is calibrated by immersing it in a beaker of standard solution of potassium chloride and comparing its output with the known value of a standard concentration. Each applicable range of the conductivity sensor is calibrated at three points by using potassium chloride standard solution at or near 15, 50, and 100 percent of full scale. Each range is checked for temperature compensation, using solutions of potassium chloride having values of conductivity near the midscale of each range.

Water Temperature

118. Water-temperature sensors are included in both of the Martek sensor packages, but two different transducers are used. The Mark II uses a thermistor, and the Mark V uses a thermolinear array. Water temperature is also measured automatically with a Lockheed Model S1071 bullet-type sensor (Figure 14), identical in physical appearance, electrical characteristics, and operating principles to the one used for measuring soil temperature (paragraphs 83-86).

119. The following are the characteristics of the two Martek temperature sensors:

	Mark II	Mark V
Range, °C	0 to +40	-5 to +45
Calibrated accuracy, °C	±0.5	±0.1
Resolution, °C	0.01	0.01

Signal conditioning

120. Signal conditioning for both Martek sensor packages is similar and is handled by a VGA board (paragraph 35) whose gain is such that 0- to full-scale output of the sensor chosen will produce a range of 0-1.0 V recorded on the cassette tape.

Maintenance

121. After each use, the sensor should be rinsed in fresh water and allowed to dry prior to storage; no other routine maintenance is required.

Calibration

122. A water-temperature sensor is calibrated by immersing it in a beaker of water and comparing its output with that obtained with a high-quality, mercury-filled, centigrade thermometer, which has been checked against a precision thermometer certified by the National Bureau of Standards. The water-temperature sensor is calibrated at three points. One point is obtained by placing the sensor in a container of stirred water near 0°C (reached by adding ice to a container of water); the second, by placing the sensor in a container of stirred water sufficiently warm to produce a reading near the full-scale value of the sensor; and the third, by placing the sensor in a container of stirred water that will produce a reading near midscale.

Water Transmissivity

123. The Martek Model XMS transmissometer (Figure 20) is a portable instrument specifically designed for optimum underwater measurements of generally turbid waters such as are found in rivers, lakes, harbors, and estuaries. It measures turbidity by determining the percent transmission of a light beam through a known path length (1/4 m) in the water. The transmissometer provides an accurate and reliable means of determining one of the fundamental optical properties of water, the beam attenuation coefficient α , a determinant of water clarity. It is very accurate, ± 1.0 percent over a wide alpha-measurement range and 1/(0.4 to 18.4 m) for a 1/4-m path length, and is ideally suited

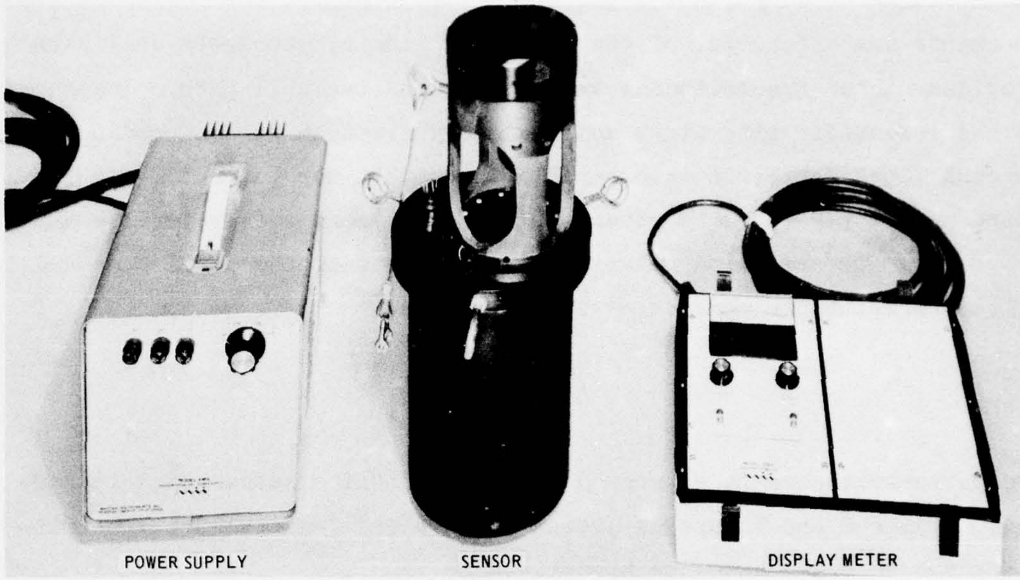

Figure 20. Martek Instruments Model XMS transmissometer (with power supply and display meter)

for water with a range from 25 to 0.01 percent transmittance (T) per metre. The useful range extends down to 10^{-6} percent T/m.

124. The Martek Model XMS electronics and sensor package consists of a solid-state electronic readout module with an a-c/d-c power supply, up to 100 m of multiconductor underwater cable with molded waterproof connectors, and an underwater folded optical path sensor with associated electronics. The readout module is housed in a compact, steel carrying case with detachable lid and canted control panel to permit moisture runoff and efficient viewing angle. Digital readout of the light transmittance measurement can be obtained instantaneously on the high-resolution, 1 percent mirrored panel meter using scales of 0-10, 0-25, and 0-100 percent T. Manual readings with the display module provide additional data for comparison with the data being recorded on cassette tape.

125. The percent T obtained with the sensor is in units of percent T per cell-path length. For a 1-m cell-path sensor, the unit measurement is percent T per metre, and for the 1/4-m cell-path sensor,

the measurement is percent T per 1/4 m. In essence, the percent T measurements are a function of the cell-path length; the 1/4-m cell path provides higher transmittance values than the 1-m cell path. Inasmuch as the scientific literature and customary practice report readings in percent T per metre, it is desirable to convert the percent T per 1/4 m to percent T per metre to obtain ready comparisons with reference data.

126. The relation between T(1/4) (transmittance per 1/4 m) and T(1) (transmittance per metre) is as follows:

$$T(1) = \left[T\left(\frac{1}{4}\right)\right]^4$$

where transmittance is expressed in absolute units rather than in percent. Table 2 and Figure 21 present equivalent 1-m absolute transmittance versus 1/4-m absolute transmittance.

127. The sensor contains a specifically designed optical system, a projection lamp, a receiver photocell, and operational amplifiers to provide a high-level signal proportional to receiver flux.

128. Characteristics of the Model XMS transmissometer are as follows:

- a. Range: 0-10, 0-25, and 0-100 percent T.
- b. Ambient light interference: negligible.
- c. Operating temperature: -2°C to +40°C.
- d. Operating depth: 0-100 m.
- e. Overall system accuracy: ±1.0 percent.
- f. Operating power: regulated self-contained; 105- to 125-V (a-c) (50/60 Hz) or 12-V (d-c) primary input.
- g. Dimensions: approximately 20-cm diam by 50 cm long.
- h. Weight: approximately 10.9 kg (24 lb).

Signal conditioning

129. Signal conditioning is accomplished with a standard VGA board (paragraph 35) set up to yield an output of 0-1.0 V, corresponding to the sensor's 0- to 0.5-V output signal.

Maintenance

130. The sensor should be rinsed in fresh or distilled water

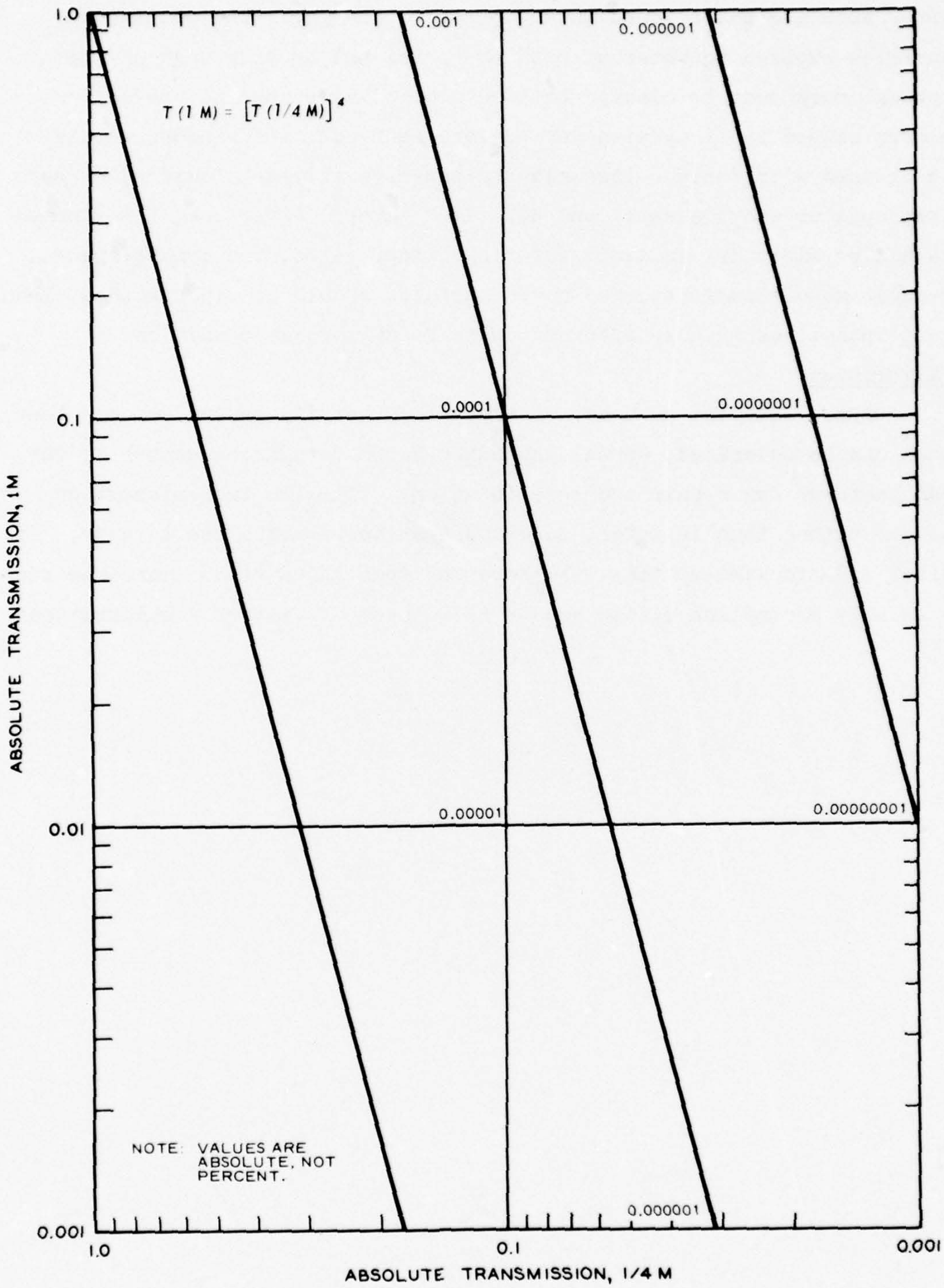

Figure 21. Curve for converting transmissivity per 1/4-m path length to transmissivity per 1-m path length

after each use and allowed to dry prior to storage. The optical surfaces exposed to water at both the prism and housing ends of the optical path must be cleaned both before and after use to prevent errors caused by dirty windows. Before each use, the windows should be cleaned with residue-free glass cleaner (e.g. lens cleaners) or pure isopropyl or ethyl alcohol and distilled water. After use, the windows should be wiped dry to avoid water spotting. Also, the control panel, readout module surfaces, and power surfaces should be wiped with a clean, damp sponge, especially after exposure to salt spray conditions.

Calibration

131. When the accuracy of the transmissivity sensor becomes less than can be tolerated, normal procedure is to return the sensor to the manufacturer for repair and recalibration. With the transmissometer in air rather than in water, zero and span adjustments can be made. If, after a 5-min warm-up time, the zero and span adjustments cannot be successfully accomplished, the sensor is in need of factory recalibration.

PART IV: TRANSLATION, PROCESSING, AND DISPLAY OF ENVIRONMENTAL DATA

Translation of Field Cassette Data to Computer-Compatible Form

132. The field station cassette data are translated to a computer-compatible input record "off-line." Off-line translation refers to preparing a magnetic tape or paper tape prior to inputting the field data to the digital equipment.

133. There are presently two methods of translating field-recorded cassette data to computer-compatible form; these include translation by use of either the Lockheed Model 251 reproducer or the Model 250 analyzer/translator.*

Translation by LEC Model 251 reproducer

134. The LEC Model 251 cassette reproducer (Figure 22) is a portable, lightweight a-c powered unit that is packaged in an attache case for protection and convenient handling. This device provides a telephone link to a teletype terminal for listing and produces a paper tape of the prerecorded field cassette data. The signal characteristics and standard accoustical coupler allow data translation directly from the field to the data reduction equipment over any commercial telephone line. This permits evaluation of the quality of the data while the personnel are still in the field, and it also allows any adjustments or repairs to be made to the field stations or sensors at once as may be indicated by the data. This capability of the translation section has proven to be a most important feature of the data-gathering system.

135. The reproducer's main function is to convert the binary recorded cassette data (format in paragraph 23) to ASCII code necessary for standard teletype operation. Each data word (record) is converted

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* Both models are manufactured by Lockheed Electronics Company (LEC), Azusa, California.

Figure 22. Lockheed Model 251 cassette reproducer

to a 3-digit BCD word and temporarily stored in a 12x32 register. The reproducer's register permits storage of up to 32 three-digit BCD words, each word consisting of three 4-bit digits. Each data word stored in memory is then retrieved in the same sequence as it was stored and combined with teletype command codes to write a 3-digit BCD word. The BCD data are then printed out by the teletype (Figure 23) and also placed on paper tape for use as input to the WES PDP-15/30 digital system.

136. An instruction manual on the use of LEC Model 251 cassette reproducer is available at the WES or can be obtained from Lockheed Electronics Company, Inc., Azusa, California.

Translation by LEC Model 250 analyzer/translator

137. The LEC Model 250 analyzer/translator (Figure 24) is a lightweight, battery-powered (and 110-V a-c) unit for monitoring, in real time, sensor data being recorded by the field station (Part II) or for translating and displaying the data from a prerecorded cassette

Preselected Interrogation Period 15 min	3-Digit BCD Data on 22 Channels								
1	002	000	369	000	255	212	241	580	-channels 1-8
	000	000	741	000	076	800	033	033	-channels 9-16
	000	000	000	000	033	033			-channels 17-22
2	003	000	386	000	254	210	241	584	
	000	000	884	000	042	802	033	033	
	020	007	000	000	033	033			
3	004	000	387	000	252	211	241	591	
	000	004	571	000	357	794	033	033	
	000	000	000	000	033	033			
4	000	000	392	000	249	218	239	584	
	000	000	602	000	102	783	033	033	
	000	000	000	000	033	033			
5	001	000	374	000	267	214	239	587	
	000	000	855	000	112	778	033	033	
	000	000	000	000	033	033			
6	002	000	391	000	268	210	241	576	
	000	000	876	000	042	791	033	033	
	004	000	000	000	033	033			
7	003	000	381	000	257	218	241	575	
	000	000	593	000	200	790	033	033	
	000	000	000	000	033	033			
8	004	000	382	000	253	217	241	565	
	000	012	112	000	692	778	033	033	
	000	000	000	000	033	033			
9	005	000	397	000	267	214	240	557	
	008	000	217	000	611	770	033	033	
	000	000	000	000	033	033			
10	006	000	377	000	258	214	236	552	
	000	000	174	000	131	769	033	033	
	009	004	000	000	033	033			
11	007	000	375	000	268	208	230	552	
	000	009	110	000	305	768	033	033	
	007	000	000	000	033	033			
12	008	000	406	000	263	215	234	550	
	047	008	048	000	536	767	033	033	
	013	000	000	000	033	033			
13	009	000	407	000	268	213	233	551	
	040	000	068	000	140	767	033	033	
	008	000	000	000	033	033			

Figure 23. Example of cassette data translated by Lockheed 251 reproducer and printed on standard teletype

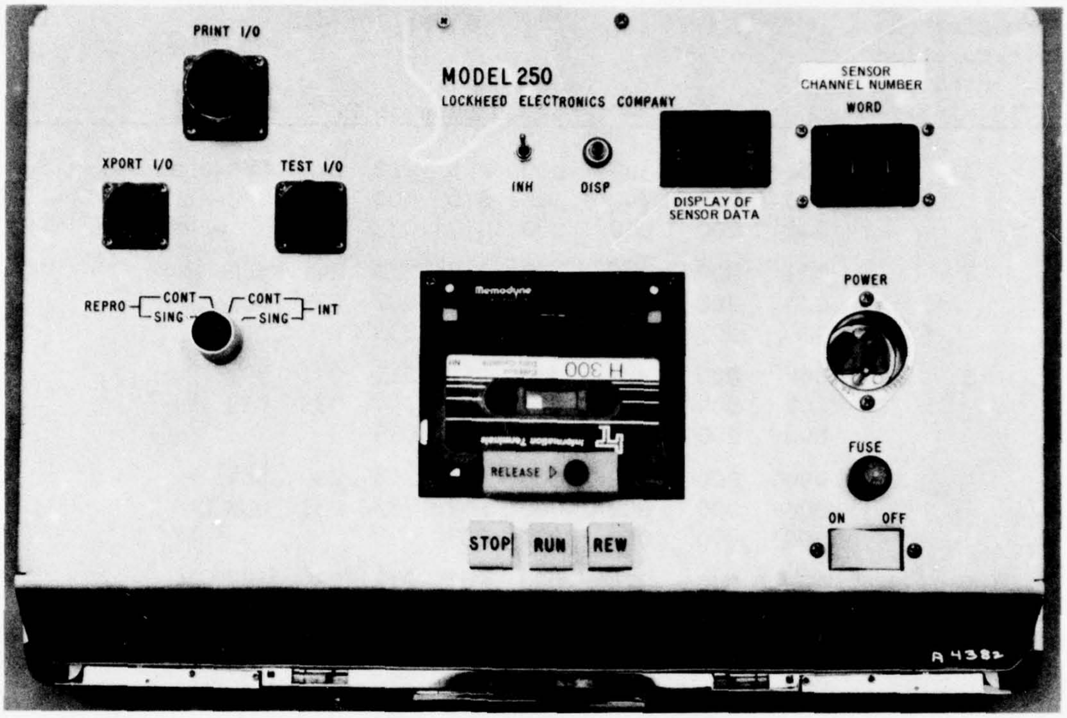


Figure 24. Lockheed Model 250 cassette analyzer/translator

tape. The unit is contained in an attache case that measures 45 by 35 by 15 cm and weighs approximately 4.54 kg, including the internal power supply (12-V battery). When used as a monitor, the analyzer/translator is connected directly to the field station as shown in Figure 25, and a display of the BCD data on each of the sensors can be obtained without disrupting normal sampling and recording by the field station.

138. In addition to the real-time monitoring capability of the analyzer/translator, it can also play back a prerecorded field cassette tape for check and verification of station and sensor performance. Data on each of the sensors can be viewed on the "data display" of the unit (Figure 24), or it can be printed out with a Hewlett-Packard* Model 5055A digital printer that can be interfaced with the unit (Figure 26). Cassette data can also be transferred to a magnetic tape by using a 7-track incremental Digi-Data Corporation** Model 1430 magnetic tape recorder

* Hewlett-Packard, Inc., Copertino, California.
** Digi-Data Corporation, Bladensburg, Maryland.

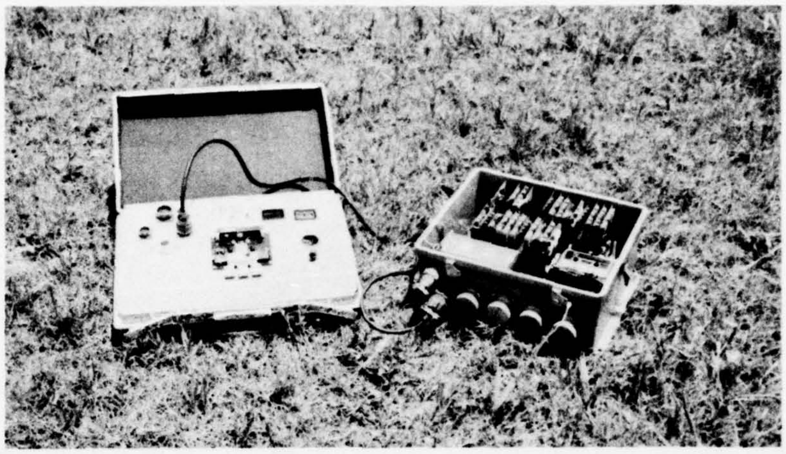


Figure 25. LEC Model 250 analyzer/translator
connected to field station

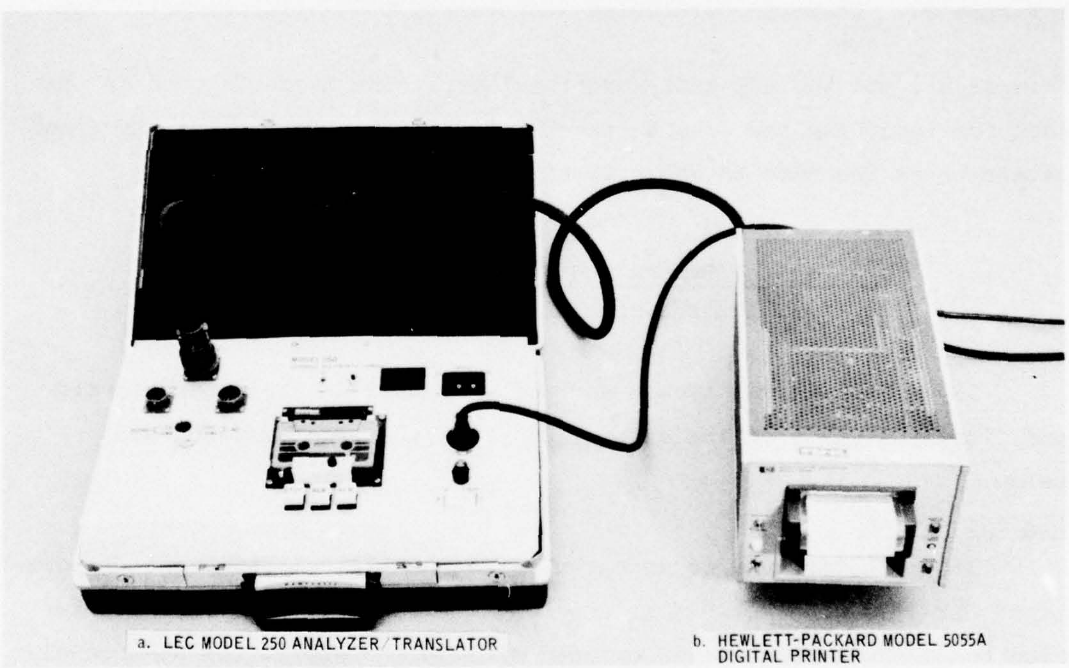


Figure 26. Cassette data being listed with LEC analyzer/translator
and Hewlett-Packard digital printer

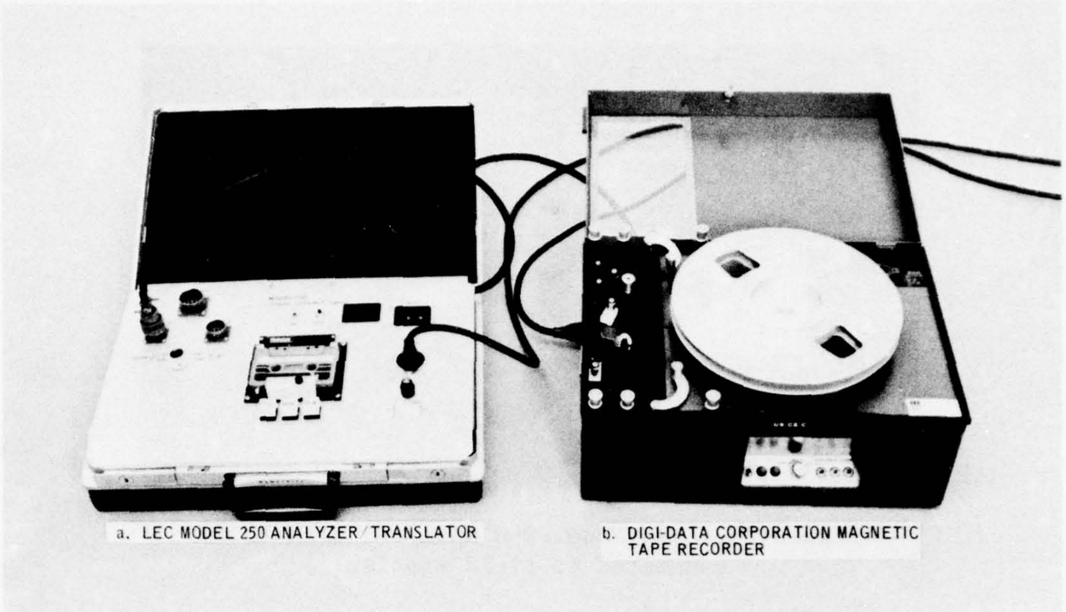


Figure 27. Cassette data being transferred to 7-track magnetic tape

(Figure 27) and the LEC analyzer/translator. The magnetic tape is then used for inputting the data to the PDP-15/30. The format for the final data tape is the same as shown in Figure 23.

Digital System and Software for Reading, Computing, and Displaying Sensor Data

139. The digital system and software used in the data analysis and display section of the automated system are briefly discussed below.

Digital system

140. The primary equipment used is the Digital Equipment Corporation* PDP-15/30, although a second system (Scientific Control Corporation Model 650), which is interfaced with the PDP-15/30 for additional memory and operating functions, is also used. In a number of respects, the two systems are parallel: both have high-speed paper tape readers,

* Digital Equipment Corporation, Maynard, Massachusetts.

100 channels of A-D conversion, and teletypes. Interfaced with the WES PDP-15/30 is a 16K memory, a real-time clock, high-speed paper tape reader and punch, multistation teletype control, a FORTRAN IV capability, a 600 line/min printer, 9-track magnetic tape handler, CRT display console, Calcomp drum plotter, and teletype access capability via accoustic coupler from the LEC field station. The various components of the two systems are illustrated in Figure 28.

Software

141. The conversational software reads the field data as input by paper or magnetic tape, edits the data when required, associates the proper calibration (Table 3) and function with each data channel, and displays the results in tabular and graphic forms. The primary equipment used is the PDP-15/30 described in paragraph 140. The software is modular in form with a module (or subroutine) included for each particular sensor and function. New modules representing new sensors and their respective calibrations can be added at any time. The main program takes the input data file (or the edited data file), associates the numerical value in each channel with the units of measure corresponding to the appropriate sensor, and calibrates the value with respect to the characteristics of the particular sensor. The interpreted data for all channels are then printed in columnar format with the date (day, month, and year) and the associated time (hours and minutes) of sampling.

142. The conversational program is structured in such a way as to permit maximum flexibility in the display of the information; i.e., any data channel can be associated with any other data channel and the output can be described in either graphic or mathematical terms. That is, all variable characteristics of the data collection are independent and can be specified with the program control. Further, the user can indicate the final form of the data, having hard copy (tabular and graphic forms), paper tape, or magnetic tape available to him.

143. In some cases, field data errors will exist. They may be caused by noise on the telephone link or in the tape drive, a poor electrical lead from the sensor to the recorder, or a transient malfunction of a sensor due to some unexplainable event, such as a bird sitting

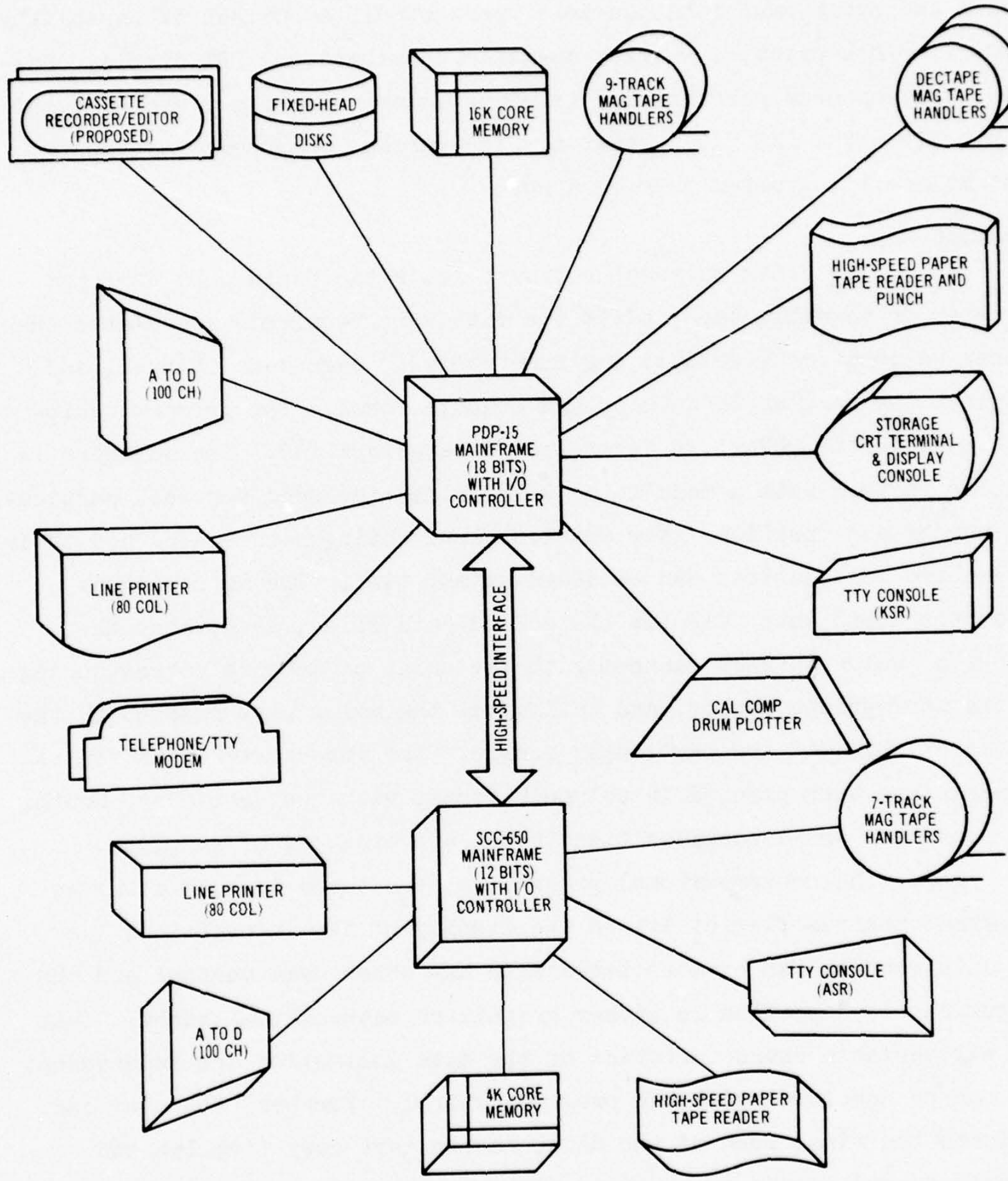


Figure 28. WES PDP-15/30 and SCC-650 digital systems

on the wind-direction sensor. Software has been developed for data editing in such cases, and the accuracy of the data can be noted in the final printout through use of the editing program.

PART V: FIELD DEMONSTRATION OF THE SYSTEM

144. The automated data acquisition system discussed in the preceding parts, i.e. the field station, sensors, translation equipment, and software that controls the analysis and portrayal of data, has undergone considerable testing and evaluation. However, demonstration of its capability and reliability when the field station is in diverse and remote areas was necessary before the system could be used with confidence by facility personnel. Since September 1974, field stations have been installed in various locations. This section of the report describes the test locations, sensors used, and data collected and then summarizes the performance of the field stations and sensors at each location. Examples of how the measured data can be portrayed once they have been translated and processed are also presented.

Test Locations and Data Collected

145. The following geographic locations were selected for detailed field evaluation and demonstration of the field station and selected sensors:

- a. Pine Bluff Arsenal, Arkansas
- b. Fort Carson, Colorado
- c. Fort McClellan, Alabama
- d. Upper Blakely Island, Mobile, Alabama
- e. Satartia, Mississippi

The types of sensors and the sites at which they were used at each respective location are discussed below.

Pine Bluff Arsenal, Arkansas

146. From 1 September 1974 through 30 May 1975, the WES used two 32-channel field stations and a selected group of sensors to monitor environmental conditions at two sites at the Pine Bluff Arsenal on a small stream (White Phosphorous (WP) Creek): one receives drainage from a portion of the installation, and the other, liquid wastes from an ammunition manufacturing plant (Figure 29).

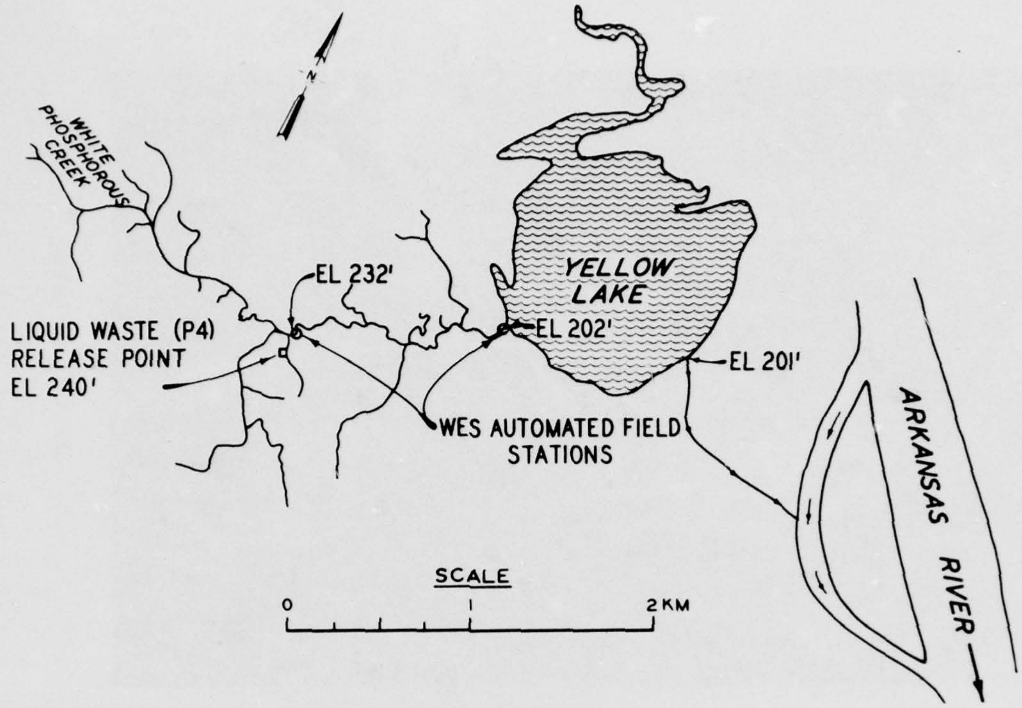


Figure 29. Location of WES field sites at Pine Bluff Arsenal, Pine Bluff, Arkansas

The upstream site (Figure 30a) was approximately 60 m downstream from the liquid waste release point (military coordinates 846964), and the downstream site (Figure 30b) was on the same stream just above the point (military coordinates 855969) where the stream empties into Yellow Lake (Figure 29). The approximate land area of the WP Creek drainage basin is 2.083 km^2 above the upstream site and 3.061 km^2 above the downstream site.

147. The sensors listed below were used at each site.

a. Solar radiation (Matrix Mark I-G)

b. Wind speed

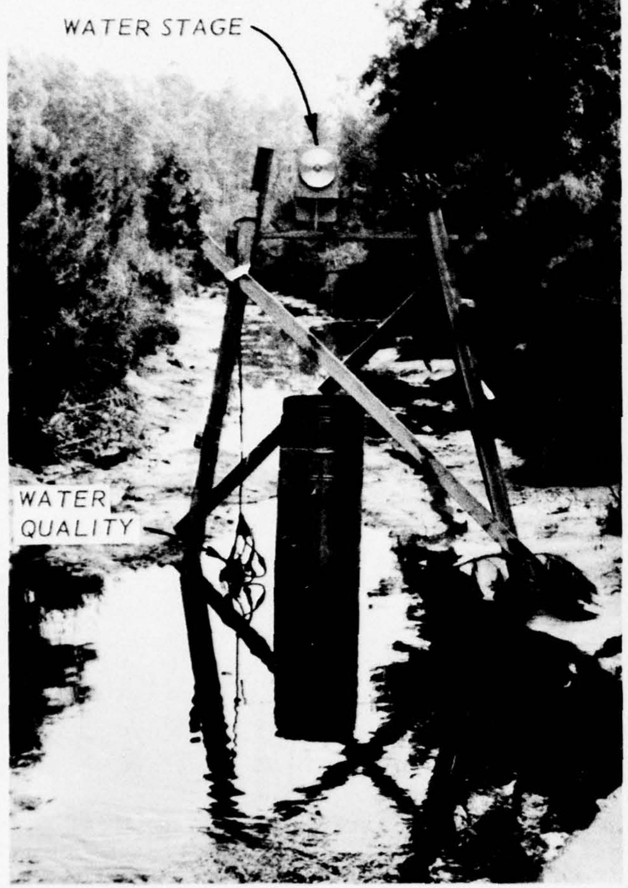
c. Wind direction

d. Rainfall

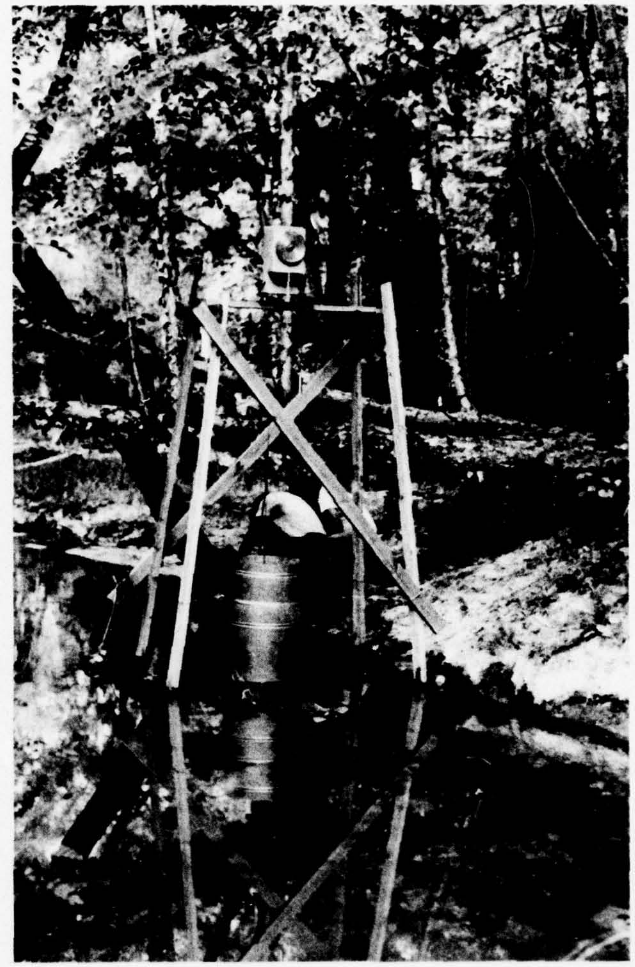
e. Soil temperature

f. Water level (2)

g. Water velocity



a. Upstream site



b. *Downstream site*

Figure 30. Sites at Pine Bluff Arsenal on White Phosphorous Creek selected for environmental monitoring

h. pH (Martek Mark II)

i. D.O. (Martek Mark II)

j. Conductivity (Martek Mark II)

k. Water temperature (Martek Mark II)

At the upstream site, a second water-level sensor (Figure 31) was used, in addition to the one described in paragraphs 87-89, to determine the amount of liquid waste being discharged into the stream from the ammunition manufacturing plant.

148. The field stations were used with an initially (September 1974) preselected sampling interval of 15 min, which was later changed (February 1975) to a sampling interval of 30 min.

Fort Carson, Colorado

149. From 20 November 1975 through 30 May 1976, the WES used three field stations with appropriate sensors at three sites at Fort Carson, Colorado. Two stations were used to collect meteorological data at Red Devil (Figure 32) and Turkey Creek (Figure 33). The other station was used to collect data on water quality on Clover Ditch (Figure 34).

150. The sensors used are as follows:

a. Two meteorological sites: (Military coordinates 146536 and 074636)

(1) Rainfall

(2) Wind speed

(3) Wind direction

(4) Air temperature

(5) Solar radiation (Matrix Mark I-G)

b. Water-quality site: (Military coordinates 303858)

(1) Rainfall

(2) pH (Martek Mark II and V)

(3) D.O. (Martek Mark II and V)

(4) Conductivity (Martek Mark II and V)

(5) Water temperature (Martek Mark II and V)

151. The field stations initially used a 60-min sampling interval, but the water-quality station was changed to a 30-min interval

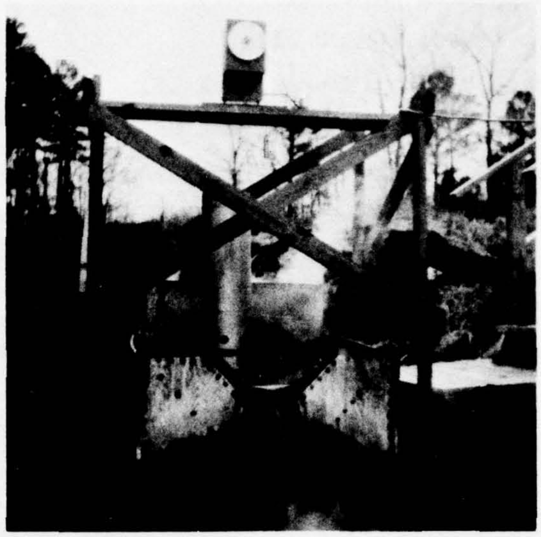
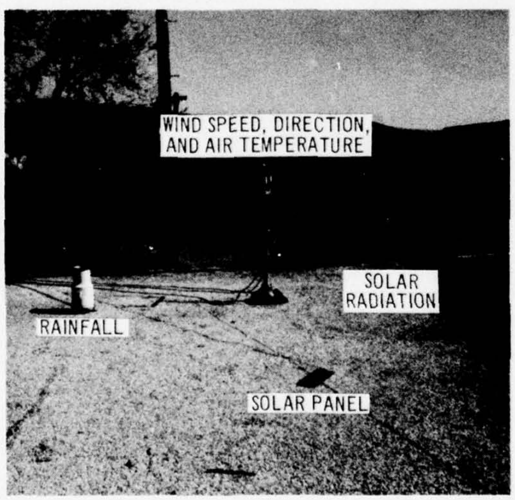
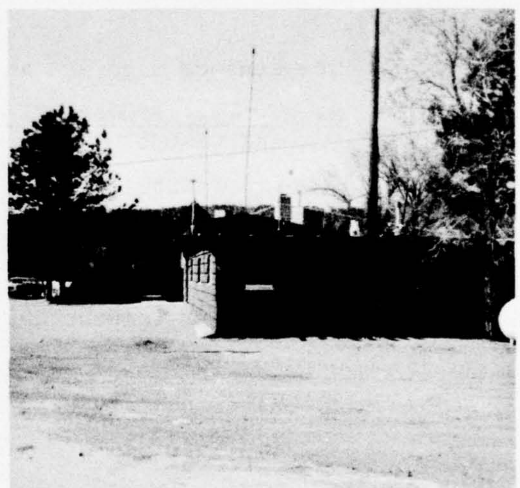


Figure 31. Automatic measurement of water level in a 90-deg V-notched weir box at the upstream site at Pine Bluff Arsenal



a. Sensors



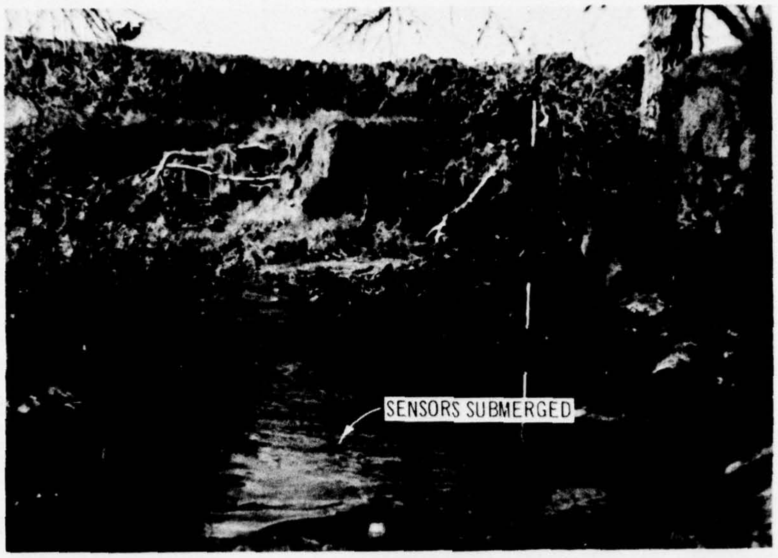
b. Field station on roof

Figure 32. Automated meteorological field station at Red Devil, Fort Carson, Colorado

SENSORS

- RAINFALL
- WIND SPEED
- WIND DIRECTION
- AIR TEMPERATURE
- SOLAR RADIATION

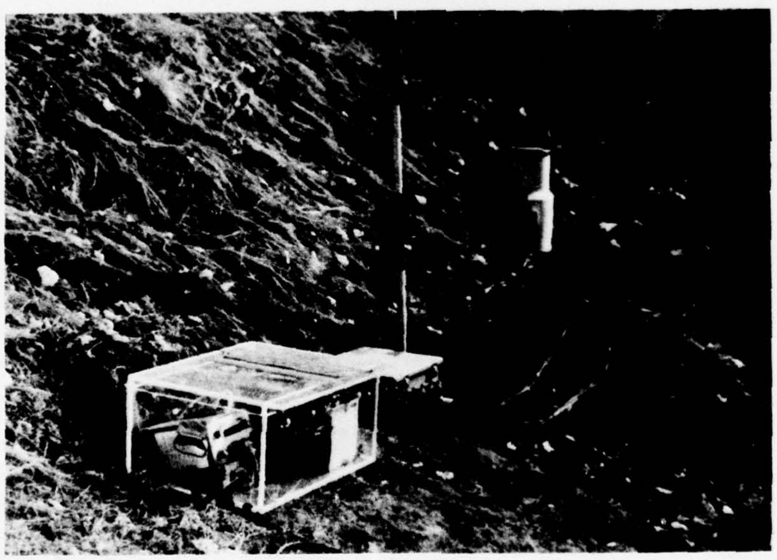
Figure 33. Automated meteorological field station at Turkey Creek, Fort Carson, Colorado



SENSORS

- pH
- DISSOLVED OXYGEN
- CONDUCTIVITY
- WATER TEMPERATURE

a. Sampling site for water-quality data



- RAINFALL

b. Automated field station set on 1-hr sampling interval

Figure 34. Water-quality monitoring on Clover Ditch, Fort Carson, Colorado

at different times during the field demonstration.

Fort McClellan, Alabama

152. From 12 November 1975 through 30 May 1976, the WES used one field station at Fort McClellan, Alabama, on Cane Creek at military coordinates 014323 (Figure 35). The following six sensors collected environmental data pertaining to water quality and rainfall:

a. D.O. (Martek Mark V)

b. pH (Martek Mark V)

c. Conductivity (Martek Mark V)

d. Water temperature (Martek Mark V)

e. Transmissivity

f. Rainfall

Two sampling intervals of 30 and 60 min were used on different occasions for collecting environmental data at this site.

Upper Blakely Island, Mobile, Alabama

153. Figure 36 shows the field station that the WES used at Upper Blakely Island, Mobile, Alabama (latitude 88°01' and longitude 30°44'), between 18 December 1975 and 30 May 1976. The sensors used to collect meteorological and soil data are as follows:

a. Rainfall

b. Wind speed at 2 m above ground

c. Wind speed at 8 m above ground

d. Wind direction at 2 m above ground

e. Wind direction at 8 m above ground

f. Solar radiation (two Matrix Mark I-G sensors at 2 m above ground)

g. Surface soil temperature

h. Soil temperature at 1.52-m depth

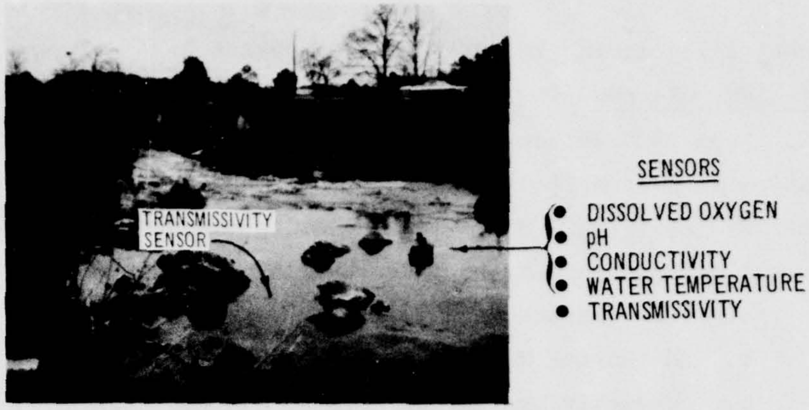
i. Air temperature at 2 m above ground

j. Pan water level and evaporation at 0.7 m above ground

Intervals of 15, 30, and 60 min were used at different times during the data-collection effort.

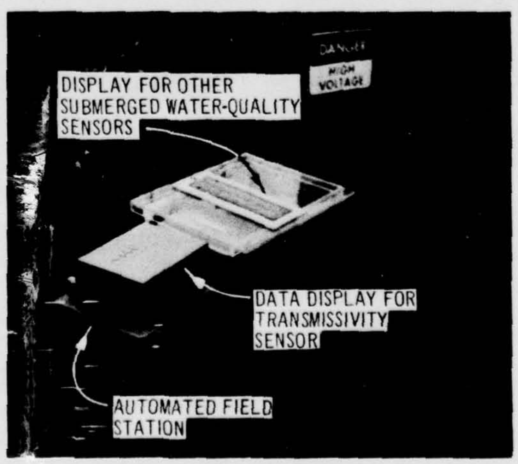
Satartia, Mississippi

154. From 2 November 1975 through 21 November 1975, the WES used



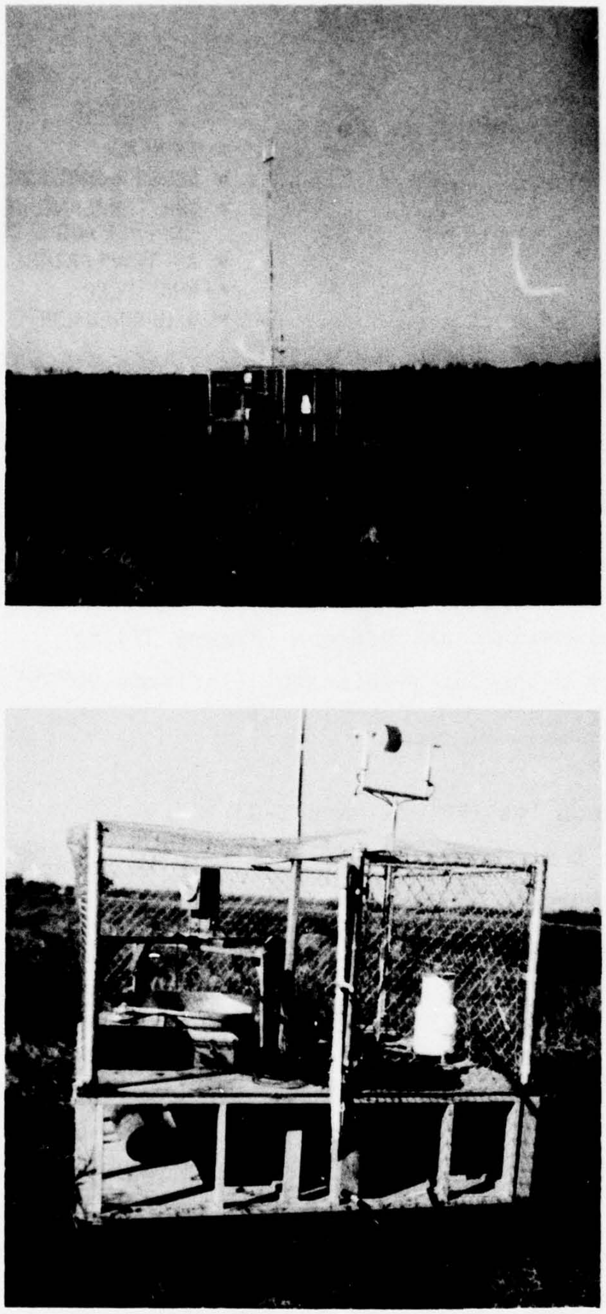
a. Water-quality sensors (submerged)

b. Field station and rain gage



c. Instrumentation

Figure 35. Monitoring of water quality on Cane Creek, Fort McClellan, Alabama



SENSORS

- RAINFALL
- WIND SPEED (2M AND 8M)
- WIND DIRECTION (2M AND 8M)
- SOLAR RADIATION
- SOIL TEMPERATURE (SURFACE AND 1.5-M DEPTH)
- AIR TEMPERATURE
- EVAPORATION

Figure 36. Automated field station and sensors at Upper Blakely Island, Mobile, Alabama

Figure 37. Meteorological field station at Satartia, Mississippi

one field station and the following eight sensors (Figure 37) to collect environmental data at Satartia, Mississippi (latitude 90°35' and longitude 32°33'):

- a. Rainfall
- b. Solar radiation (two Matrix Mark I-G)
- c. Surface soil temperature
- d. Soil temperature at 30-cm depth
- e. Air temperature
- f. Wind speed
- g. Wind direction

All data were collected at a sampling interval of 15 min.

Performances of Field Stations and Sensors

155. For the purposes of this evaluation, a satisfactory record for the field station was considered to be a daily record in which the data for 75 percent of the sensors were reliably recorded. The performances of the various field stations and sensors are summarized in Table 4 in terms of the error rate and major types of equipment

malfunctions. The error rate in percent was computed by the following equation:

$$\frac{\text{Number of days deployed - number of satisfactory records}}{\text{Number of days deployed}} \times 100$$

The following paragraphs present discussions on the types and reasons for equipment malfunctions.

Pine Bluff Arsenal, Arkansas

156. As shown in Table 4, the error rates for the two stations at Pine Bluff Arsenal, Arkansas, were 48 and 40 percent, respectively. During the initial phase of these field trials, many malfunctions occurred. At the outset (September 1974), only a limited amount of software for data reduction had been developed, and the equipment for field data verification (LEC 251 reproducer and 250 translator) had not undergone extensive testing and evaluation. As a result, the lag time in translating cassette data into engineering units was far too great and resulted in insufficient feedback information for proper maintenance of the field station and sensors.

157. The problems encountered at Pine Bluff Arsenal were quite numerous with both the field station and most of the sensors. Problems occurred with the power supply, timing circuits, and cassette tape and recording electronics.

158. The power supply problems resulted primarily from extended use of the station's battery. For example, on the first, second, and third visits to the sites (visits were at 3-week intervals), the station's battery was below 11 V, the minimum voltage required for acceptable performance. A thorough examination of the recorded tape data revealed that only 12 to 18 days of reliable data had been recorded for each data-collection period. A check of the timing system revealed that the automatic shutdown feature, which limits use of the station's power supply (paragraph 12) in the event that normal sampling sequence fails, had malfunctioned. This malfunction resulted in overuse of the battery for all three data-collection periods.

159. Another problem that emerged in the demonstration at Pine

Bluff Arsenal involved the cassette recording tapes. The cassette tapes initially used with the system had not been designed for use in widely varying temperature and humidity environments. As a result, the tapes were not always geometrically stable and, therefore, would not feed through the recording system smoothly enough to permit adequate recording in extreme conditions of temperature and humidity. Toward the end of the Pine Bluff Arsenal data-collection exercise (April-May 1975), the WES started using H-series (hostile-environment) digital cassette tapes, manufactured by the Information Terminals Corporation (paragraph 20). These cassette tapes performed quite satisfactorily for recording environmental data with the field station.

160. Additional problems surfaced in the demonstration at Pine Bluff Arsenal with the power supply units of the Martek Mark II water-quality sensor package. This sensor package contains probes for measuring pH, conductivity, D.O. and water temperature and requires +12 V of external power (paragraph 102). The calculated power drain from the Mark II unit indicated that the water-quality system could perform as long as 12 to 15 days without recharging; however, on several occasions (i.e. different data-collection periods), the data that were recorded on cassette tapes indicated that the current drain was probably a great deal more than was previously indicated. This was later proven true and was a result of a malfunction in the electronics that delivered power to the sensor system.

161. Problems also emerged at Pine Bluff Arsenal with contamination of the individual Mark II water-quality probes (pH, conductivity, and D.O.); however, because of the other malfunctions discussed above, it was impossible to obtain sufficient data from the records to develop specific maintenance guidelines for the probes, i.e. to specify maximum time intervals between cleaning of the probes. This was accomplished later using data obtained from the tests at Fort Carson, Colorado (paragraphs 167 and 168).

162. Even though numerous problems occurred with the field station and sensors during the Pine Bluff Arsenal tests, approximately 56 percent of the data were considered reliable (based on an average

error rate of 44 percent, Table 4). The total quantity of data (≈57,000 pieces of data) collected was very large as a result of the 15- and 30-min sampling intervals used.

Fort Carson, Colorado

163. The three field stations that were established for collecting meteorological and water-quality data at Fort Carson, Colorado, performed reasonably well as indicated in Table 4. The station and the six environmental sensors used at the Red Devil site performed without any major system malfunctions, as evidenced by the extremely low error rate of less than 2 percent; however, the stations and sensors used at the Turkey Creek and Clover Ditch sites resulted in error rates of 33 and 38 percent, respectively, indicating only 67 and 62 percent satisfactory data.

164. The main problems encountered at the Turkey Creek and Clover Ditch sites were with the field station's timing circuits. Both stations were set up at the same time (November 1975), and both were subjected to wide ranges of temperature (-20 to +20°C) and humidity ranges (15-75 percent). As a result of the first part of these demonstrations, it was concluded that certain parts of the electronics of the timing circuits were somewhat unreliable when operating under low (<0°) temperature and high (>60 percent) humidity ranges.

165. During March-April 1976, high-reliability timing circuits were added to the Turkey Creek and Clover Ditch field stations, and no problems were encountered with the timing systems after that time.

166. The field station used at the Clover Ditch site provided data for evaluation of the Martek Mark II and V water-quality (pH, conductivity, D.O.) sensors. The stream selected for the field demonstration received liquid wastes from the installation's sewage treatment plant and also drainage from vehicle washracks, as well as surface runoff from the post cantonment area. This evaluation took place during the dry season, i.e. November-May 1975, and therefore, very little surface runoff was received by the stream because of the limited amount of rain and snow that fell during that time. For this reason, there was relatively little suspended material in the water to

contaminate the pH, conductivity, and D.O. sensors. Even so, study of the sensors revealed that the quality of the data was degraded after the sensors had been in the water longer than 6 to 10 days.

167. To ensure the recording of high-quality data, maintenance guidelines were developed and put into practice at Clover Ditch. These guidelines require semiweekly inspection of the probes. The maintenance after inspection depends on the in situ characteristics of the water body being monitored and the frequency and duration of local rainfall and surface runoff and debris carried by the stream.

168. The on-site maintenance procedures developed for the Martek Mark II and V water-quality sensor packages (pH, conductivity, D.O., and water temperature) include servicing the probes on a weekly basis unless it is determined from the semiweekly inspection visits that the probes have been contaminated or damaged by increased surface runoff or debris carried by the stream. If the probes are determined to be working unsatisfactorily, maintenance must be performed at that time.

169. Some malfunctions of the Martek Mark II and V water-quality sensor packages were attributed to the batteries in the internal power system becoming excessively low. The wet-cell batteries of both sensor packages required recharging after approximately 12 to 15 days of use. As a result of these power problems, a solar panel and regulator that delivers sufficient continuous power (170 mA) to the sensors should be included with the system. This would decrease the maintenance time now required for servicing the batteries and also provide the required voltage for acquisition of reliable data.

170. During the Fort Carson demonstration, the LEC 250 analyzer/translator was field tested for verification of field station and sensor performance. Minor problems did emerge with the electronics of the unit, but they were corrected by LEC after consultation with the WES personnel.

Fort McClellan, Alabama

171. One field station and six environmental sensors were used at Fort McClellan, Alabama, for collecting data on water quality and rainfall. This particular station was set up at the same time (November

1975) as the field stations at Fort Carson, and some of the same malfunctions that occurred at Fort Carson also occurred with the station at Fort McClellan. The amount of satisfactory data (Table 4) at Fort McClellan was higher (76 percent, i.e. an error rate of 24 percent) than at Fort Carson, primarily because maintenance was being performed based on feedback information that was being generated with the demonstration work being conducted at the different sites. The main problems that occurred at Fort McClellan were with the field station timing mechanism and the water-quality probes as discussed below.

172. The problems with the system's timing mechanism were minimized by making some design changes (November 1975) in the timing circuits. These changes were later (March-April 1976) adopted, and as a result, additional problems with the timing circuits did not materialize.

173. The problems with the probes of the Martek water-quality sensor packages resulted from high-water stage conditions and debris carried by the stream. These conditions caused severe damage to the pH and D.O. probes. As a result, these two probes had to be replaced on two different occasions. On both occasions, the water in the stream rose exceptionally fast from heavy rainfall and surface runoff and caused the anchoring cables to become loose, thereby allowing the probe package to be subjected to considerable external forces. This problem resulted in the breakage of the two probes and thus some loss of data before they could be replaced.

Mobile, Alabama

174. One field station and 11 environmental sensors were used at Upper Blakely Island, Mobile, Alabama, from 18 December 1975 through 30 May 1976. As shown in Table 4, the error rate was 31 percent, indicating satisfactory records about 69 percent of the time; thus, considerable useful data were collected. The main differences in the demonstration at Mobile and those at Fort McClellan and Fort Carson were the number of sensors and the sampling intervals used. For the Mobile tests, intervals of 15, 30, and 60 min were used, and this resulted in a large volume of recorded cassette data (in excess of 40,000 pieces of data).

175. The problems that occurred at Mobile were with the timing

mechanism, signal-conditioning electronics, and cassette tape transport mechanism as discussed below.

176. The problem with the timing mechanism was basically the same as that that occurred at the other demonstration sites; however, this particular problem was minimized by changing (i.e. updating) the timing circuits early (February 1976) in the demonstration period. The timing problem resulted in the loss of data for only about 15 days during the Mobile demonstration work.

177. Problems also developed with the signal-conditioning circuitry (VGA board). This particular circuitry amplifies low-level input signals from the different types of sensors used with the field station. The main problem with the VGA board was a failure in the integrated circuit that controls the sequencing of incoming sensor signals. This particular problem caused a loss of data for about 12 days.

178. The problem that developed with the cassette tape transport mechanism caused a loss of data for about 8 to 10 days and was a result of a bad alignment of the magnetic tape and the pinch-belt tape driver (paragraph 19). This particular problem was, most likely, a failure of the instrumentation personnel to check the tape alignment prior to leaving the site. This particular maintenance check is a part of the normal instrumentation inspection procedure.

Satartia, Mississippi

179. One field station and seven sensors were used at Satartia, Mississippi, from 2 November through 21 November 1975. As shown in Table 4, the error rate was 5 percent, indicating that satisfactory records were obtained approximately 95 percent of the time using sampling intervals of 15 min. This short-term data collection period resulted in approximately 2000 pieces of reliable data for the various sensors used.

180. The only minor problem that emerged during this 21-day demonstration period was with the calibration of one of the solar radiation sensors. The sensor would not remain in calibration and had to be returned to the factory for repair.

Summary remarks

181. The preceding paragraphs reiterate that the field station

and sensors can be used to acquire relatively large quantities of various kinds of environmental data. The main loss of data at all of the demonstration sites resulted from the fact that maintenance of the field stations was performed at 3- to 5-week intervals. Also, most of the losses occurred during the first and second months of use, indicating that during the initial setup of the instrumentation, checks should have been made at least semiweekly until all component parts of the system had been fully checked and had been shown to be operating satisfactorily. Power consumption should have been measured over several interrogation periods, with all sensors interfaced with the field station.

182. Since all instrumented systems will, most likely, require some maintenance to keep them operating at a satisfactory level, a way to check the operation remotely would be advantageous, possibly through use of a satellite telemetering link as part of the overall data acquisition system. This would allow checking for problems associated with the field station and sensors, and field teams could visit the site soon after the problems had been detected.

183. The LEC 151 reproducer was also used extensively for translation of the prerecorded field cassette data into engineering units for data analysis and portrayal. The main function of the reproducer is to convert binary recorded cassette data to ASCII code necessary for standard teletype operation. This particular function was considered to be quite satisfactory, since many thousands of data sets were processed during this study. The only problem that surfaced with the LEC 151 reproducer was near the end of the entire test period (after considerable data were processed), wherein an extra bit (one number) was erratically added to one of the data fields. This particular problem was circumvented by the use of the conversational software package that was developed as part of the system.

Example Data Obtained at the Demonstration Sites

184. Each channel of the data obtained with the field station can be presented separately or with other data channel outputs; the data can

be presented in the form of tables or graphs (paragraph 142). Also, the user can obtain the data on paper or magnetic tape convenient for statistical or other analyses. In the following paragraphs, the data tabulation (computer printouts) and computer graphics are discussed and examples are given.

Computer printouts

185. Computer printouts that contain the calibrated sensor data recorded automatically with the field station were obtained for all demonstration sites. The printout contains the name and location of the test site, the record period, and the date and time each reading was made, as well as the name and unit of the environmental parameter measured (Figure 38). The format of the printout can be changed for a specific user's needs with only minor changes in the output software.

Computer graphics

186. Available software permits presentation of the data in four different graphic formats:

a. Option A: Plot of parameter versus time for a 24-hr (1-day) data-collection period.

b. Option B: Plot of parameter versus time for a data-collection period of several days or weeks.

c. Option C: Plot of parameter versus time for more than one sensor type for options A and B.

d. Option D: Plot of the average, maximum, and minimum parameter values versus time for a specified data-collection interval.

Examples of options B and D are shown in Figures 39 and 40, respectively. Other formats can be readily programmed as desired by the user.

ENVIRONMENTAL DATA
ON
UPPER BLAKLEY ISLAND DISPOSAL AREA
MILITARY COORDINATES 610732
MOBILE ALABAMA
RECORD PERIOD: 9 JAN -15 JAN 1976

DATE DA MO YR	SAMPLE TIME HR MN	RAIN MM	WIND SPEED M/SEC	WIND SPEED M/SEC	SOLAR RADIATION MW/SQCM	SOLAR RADIATION MW/SQCM	WIND DIRECTION DEG,N	WIND DIRECTION DEG,N	SOIL TEMPERATURE DEG,C	SOIL TEMPERATURE DEG,C	AIR TEMPERATURE DEG,C	EVAPORATION CM
(SENSOR NO.)		2	3	5	6	7	8	9	10	11	12	13
13 1 76												
	10*15	0.00	4.12	2.43	7.76	11.55	157.00	179.50	17.90	12.80	16.20	27.13
	10*30	0.51	5.18	3.92	6.55	0.00	135.50	183.50	17.90	12.80	16.30	27.13
	10*45	0.00	5.28	4.06	5.11	0.00	151.00	202.00	17.90	12.90	16.40	27.13
	11* 0	0.00	5.30	3.69	26.35	0.00	142.00	186.50	17.90	13.00	16.20	27.20
	11*15	0.00	5.16	4.07	13.74	0.00	146.00	179.00	17.90	13.00	16.80	27.20
	11*30	0.00	5.09	4.24	48.20	0.00	136.50	170.50	17.90	13.10	16.80	27.13
	11*45	0.00	4.70	4.58	12.52	0.00	153.00	192.00	17.90	13.20	16.60	27.05
	12* 0	0.00	4.99	3.91	6.06	0.00	145.50	180.00	17.90	13.20	17.10	27.20
	12*15	0.00	4.46	2.37	8.58	0.00	168.00	191.50	17.90	13.30	16.40	27.20
	12*30	0.00	4.47	2.47	7.05	0.00	142.00	181.50	17.90	13.40	16.90	27.13
	12*45	0.00	5.05	3.51	6.18	0.00	143.50	183.00	17.90	13.40	16.70	27.20
	13* 0	0.25	5.28	4.01	0.00	0.00	152.50	187.50	17.90	13.50	16.70	27.28
	13*15	1.27	3.97	2.02	5.47	0.00	153.50	204.00	17.90	13.60	16.40	27.28
	13*30	0.00	4.30	2.57	3.58	0.00	159.50	188.00	17.90	13.60	16.80	27.28
	13*45	0.25	4.78	3.43	7.17	0.00	147.00	204.50	17.90	13.70	16.80	27.20
	14* 0	0.00	4.45	3.11	5.00	0.00	138.50	182.50	17.90	13.70	16.80	27.28
	14*15	0.00	3.20	1.65	2.66	0.00	126.50	185.00	17.90	13.80	16.50	27.28
	14*30	0.00	3.10	1.50	0.00	0.00	144.00	182.00	17.90	13.80	16.20	27.28
	14*45	0.00	2.33	0.33	0.00	0.00	118.50	165.50	17.90	13.80	16.20	27.28
	15* 0	0.00	2.80	0.84	0.00	0.00	133.00	168.00	17.90	13.90	15.90	27.28
	15*15	0.00	2.76	0.88	0.00	0.00	123.00	164.50	17.90	13.90	15.80	27.28
	15*30	0.00	2.39	0.23	0.00	0.00	138.00	162.50	17.90	13.90	15.30	27.28
	15*45	0.00	2.18	0.10	0.00	0.00	138.50	175.00	17.90	14.00	15.80	27.28
	16* 0	0.00	1.59	0.00	0.00	0.00	112.50	163.00	17.90	14.00	15.50	27.28
	16*15	0.00	1.59	0.00	0.00	0.00	97.00	143.50	17.90	14.00	15.00	27.28
	16*30	0.00	2.14	0.14	0.00	0.00	112.00	149.00	17.90	14.00	14.30	27.28
	16*45	0.00	2.12	0.14	0.00	0.00	111.00	148.50	17.90	14.00	13.70	27.28
	17* 0	0.00	2.95	2.48	0.00	0.00	124.50	113.50	17.90	14.00	13.20	27.28
	17*15	0.00	1.48	0.00	0.00	0.00	95.00	142.00	17.90	13.90	13.00	27.28
	17*30	0.00	1.86	0.00	0.00	0.00	89.50	142.50	17.90	13.90	13.20	27.28
	17*45	0.00	1.78	0.00	0.00	0.00	100.00	134.00	17.90	13.90	13.00	27.28
	18* 0	0.00	1.93	0.00	0.00	0.00	90.00	138.00	17.90	13.90	13.00	27.28
	18*15	0.00	1.48	0.00	0.00	0.00	121.00	166.50	17.90	13.90	13.40	27.28
	18*30	0.00	1.96	0.36	0.00	0.00	183.00	235.50	17.90	13.90	17.20	27.28
	18*45	0.00	3.07	1.47	0.00	0.00	101.50	154.50	17.90	13.90	14.00	27.28
	19* 0	0.00	2.26	0.46	0.00	0.00	190.00	236.50	17.90	13.90	17.20	27.28
	19*15	0.00	2.72	1.24	0.00	0.00	129.00	143.00	17.90	13.80	13.60	27.28
	19*30	0.00	2.57	0.64	0.00	0.00	190.00	207.50	17.90	13.80	17.00	27.28
	19*45	0.00	4.09	2.92	0.00	0.00	198.50	223.50	17.90	13.80	17.80	27.28
	20* 0	0.00	4.69	3.17	0.00	0.00	227.00	247.50	17.90	13.80	18.00	27.28
	20*15	0.00	4.78	3.46	0.00	0.00	187.50	239.50	17.90	13.80	17.90	27.20
	20*30	0.00	4.73	4.04	0.00	0.00	233.50	270.00	17.90	13.80	18.20	27.28
	20*45	0.00	5.03	4.11	0.00	0.00	185.50	243.50	17.90	13.90	18.00	27.28
	21* 0	0.00	5.00	3.94	0.00	0.00	196.00	224.50	17.90	13.90	17.70	27.28

Figure 38. Environmental data for Upper Blakely Island, Mobile, Alabama

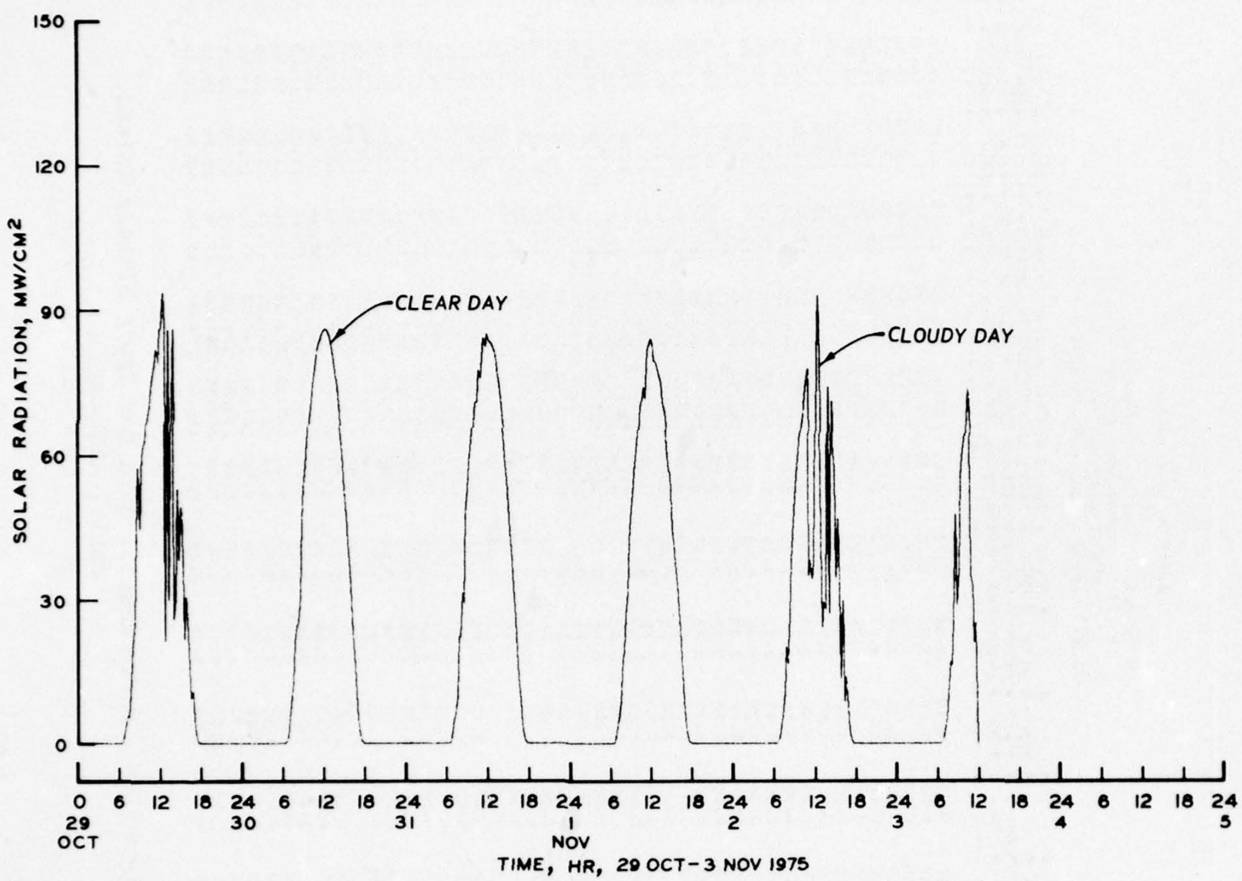


Figure 39. Example of computer printout for option B, parameter versus time for a specified period

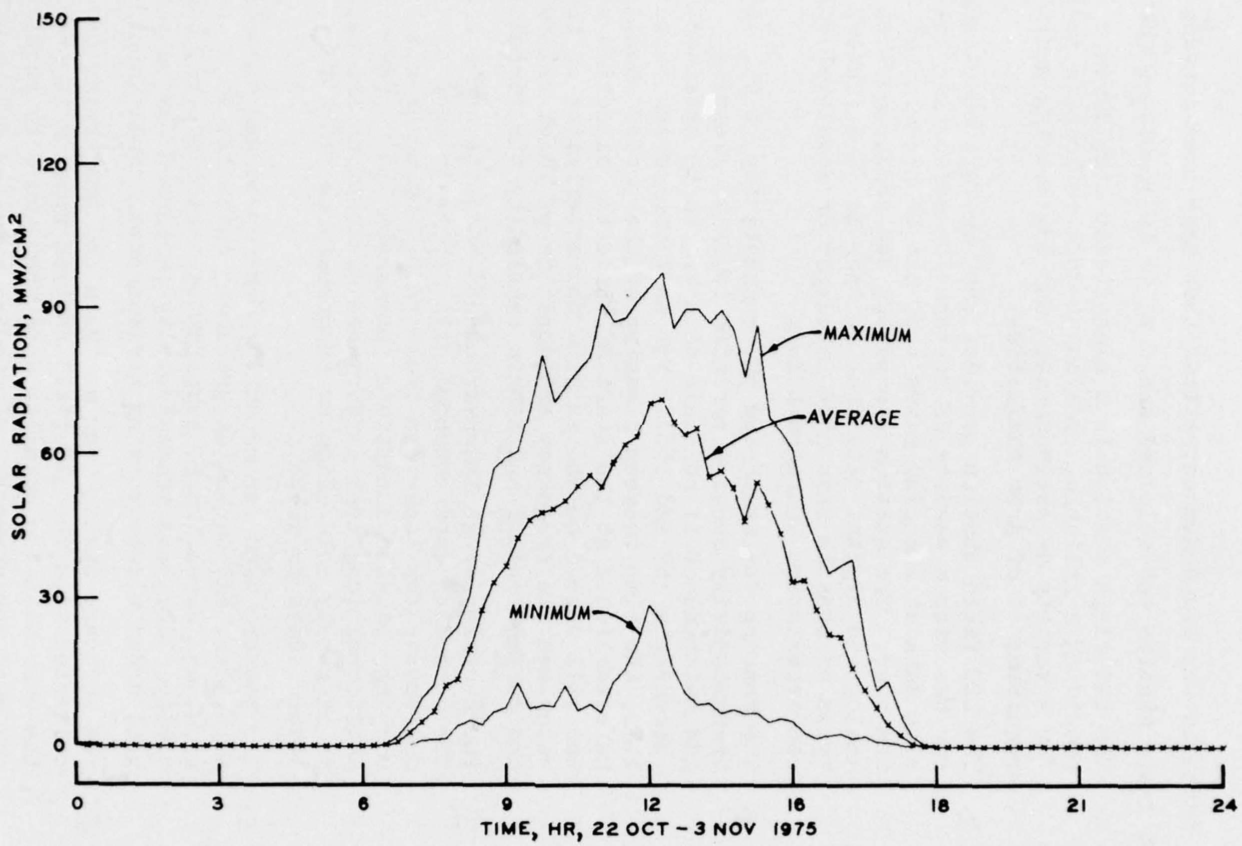


Figure 40. Example of computer printout for option D, average, maximum, and minimum values versus time for a specified data-collection interval of 15 min

PART VI: CONCLUSIONS AND RECOMMENDATIONS

Conclusions

187. Based on the field demonstrations that have been conducted with the LEC field station and selected sensors, it is concluded that:

a. The LEC field station is a significant step forward in providing a reliable, continuous data-collection device for a variety of environmental and engineering monitoring requirements of Army facilities.

b. The LEC field station provides the hardware necessary for use with a variety of sensors for collecting on-site data at sampling rates that can be preselected by the user. The station can accept and condition both analog and digital data from as many as 30 different types of sensors that have impedance or low-level voltaic characteristics (paragraph 10).

c. The sensors for measuring pH, conductivity, D.O., and transmissivity require periodic (weekly) cleaning and maintenance if reliable data are to be obtained (paragraphs 167 and 168). For most monitoring problems, the time between cleaning of the probes should be established at the start of the data-collection work and will depend on the in situ characteristics of the water and the frequency and duration of local rainfall and surface runoff and debris carried by the streams.

d. The H-series (hostile-environment) cassette tapes used for recording environmental data appear to meet the requirements for long-term field recording under widely varying climatic conditions (paragraph 159). However, additional long-term performance evaluations are needed in extremely cold climates (temperatures $<10^{\circ}C$ for several days or weeks).

e. The sensors used for measuring wind speed and direction; soil, air, and water temperatures; rainfall; solar radiation; and water level, evaporation, velocity, pH, conductivity, D.O., and transmissivity performed reasonably well under widely varying environmental conditions.

f. The software package for analysis and processing of data collected with the LEC field station appears to provide the user with the detailed data that would be required for most environmental monitoring problems. The modular construction of the software allows modification of data portrayal methods to meet specific installation

monitoring problems (paragraphs 141-143 and 182).

<u>g</u>. The present methods for verification of data while the team is still on site need improvement (paragraph 169).

<u>h</u>. The power supply systems for the Martek water-quality sensors (Mark II and V packages and XMS transmissivity sensor) need some improvement to minimize battery maintenance for remote, long-term environmental monitoring work.

Recommendations

188. Based on the results of this study, it is recommended that:

<u>a</u>. Each LEC 101R field station be equipped with a solar panel for charging the station's battery, and the station's timing circuitry be constructed with high-reliability, complementary, metal oxide semiconductor integrated circuits.

<u>b</u>. Additional research be conducted to evaluate other sensors that could be interfaced, with good reliability, with the LEC field station. Some of the sensors that are recommended for evaluation and possible interfacing are those for measuring the parameters given in Table 1.

<u>c</u>. Improvements be made in the power supply units of the Martek water-quality sensor (Mark II and V) packages for long-term monitoring problems by installing a solar panel and regulator. This will decrease the maintenance that is presently required to obtain reliable data.

<u>d</u>. Improvements be made to the equipment used for verification of the cassette data in the field. The concepts for the design of the LEC 250 analyzer/translator and 251 reproducer are well suited for on-site data verifications; however, better reliability is needed and can probably be obtained with the use of newly marketed, high-reliability integrated circuitry.

<u>e</u>. An improved instrumented system be developed for reading and transferring the cassette data into the computer so that large volumes of environmental and engineering data can be processed without the preparation of paper data tapes. This should decrease the time now required to obtain data with engineering units.

<u>f</u>. Research be conducted to develop reliable sensors for measuring in situ soil moisture.

g. The feasibility of using a satellite telemetering link to monitor station and sensor performance be investigated. If cost-effective, this would minimize the loss of data due to equipment malfunctions by dictating visits to the field when they are needed.

Table 1

Additional Parameters That Can Be Measured with Sensors Available for Use with the LEC 101 R Automated Field Station

Bromide ion	Phosphate ion
Cadmium ion	Potassium ion
Calcium ion	Power supply current and voltage levels
Chloride ion	RPM (for rotations of shaft mechanisms)
Copper ion	Relative humidity
Current direction	Salinity/alkalinity
Cyanide ion	Silver ion
Fluoride ion	Sodium ion
Fluoroborate ion	Soil-water flow
Iodide ion	Sulfide ion
Lead ion	Sulphate ion
Nitrate ion	Thiocyanate ion
Nitrite ion	Total monovalent cation
Noise level	Total divalent cation
Oxidation-reduction potential	Zinc ion
Perchlorate ion	

Table 2

Conversion of 1/4-m to 1-m Percent

Transmittance in Absolute Units

$T_{1/4}$	T_1	$T_{1/4}$	T_1	$T_{1/4}$	T_1	$T_{1/4}$	T_1
1.00	1.00	0.75	3.16×10^{-1}	0.50	6.25×10^{-2}	0.25	3.91×10^{-3}
0.99	9.61×10^{-1}	0.74	3.00	0.49	5.76	0.24	3.32
0.98	9.22	0.73	2.84	0.48	5.31	0.23	2.80
0.97	8.85	0.72	2.69	0.47	4.88	0.22	2.34
0.96	8.49	0.71	2.54	0.46	4.48	0.21	1.94
0.95	8.15	0.70	2.40	0.45	4.10	0.20	1.60
0.94	7.81	0.69	2.27	0.44	3.75	0.19	1.30
0.93	7.48	0.68	2.14	0.43	3.42	0.18	1.05
0.92	7.16	0.67	2.02	0.42	3.11	0.17	8.35×10^{-4}
0.91	6.86	0.66	1.90	0.41	2.83	0.16	6.55
0.90	6.56	0.65	1.79	0.40	2.56	0.15	5.06
0.89	6.27	0.64	1.68	0.39	2.31	0.14	3.84
0.88	6.00	0.63	1.58	0.38	2.09	0.13	2.86
0.87	5.73	0.62	1.48	0.37	1.87	0.12	2.07
0.86	5.47	0.61	1.38	0.36	1.68	0.11	1.46
0.85	5.22	0.60	1.30	0.35	1.50	0.10	1.00
0.84	4.98	0.59	1.21	0.34	1.34	0.09 ×	6.56×10^{-5}
0.83	4.75	0.58	1.13	0.33	1.19	0.08	4.10
0.82	4.52	0.57	1.06	0.32	1.05	0.07	2.40
0.81	4.30	0.56	9.83×10^{-2}	0.31	9.24×10^{-3}	0.06	1.30
0.80	4.10	0.55	9.15	0.30	8.10	0.05	6.24×10^{-6}
0.79	3.90	0.54	8.50	0.29	7.07	0.04	2.56
0.78	3.70	0.53	7.89	0.28	6.15	0.03	8.10×10^{-7}
0.77	3.51	0.52	7.31	0.27	5.31	0.02	1.60
0.76	3.34	0.51	6.77	0.26	4.57	0.01	1.00×10^{-8}

Table 3

Conversion of Automatically Recorded Sensor Data to Engineering Units

Sensor	Conversion Relation	Units
Solar radiation (Matrix Mark 1-G Sol-A-Meter)	Table lookup (voltage versus radiation)	mW/cm^2
Solar radiation (Eppley spectral pyranometer)	(Counts) 0.36847	mW/cm^2
Rainfall (weather measure model P-501)	(Counts) 0.254	mm
Wind speed (Climet Model 011-2B)	Counts (X_i) 0.44704 where X_i = constant for sampling interval as follows $X_{3min} = 0.1402$ $X_{5min} = 0.08412$ $X_{10min} = 0.04206$ $X_{15min} = 0.02804$ $X_{30min} = 0.01402$ $X_{60min} = 0.00701$ $X_{120min} = 0.00350$ $X_{240min} = 0.00175$	m/sec
Wind direction (Climet Model 012-2B)	(Counts) 0.5	Degrees clockwise from north
Air temperature (Lockheed Model S1081)	(Counts - 400) 0.1	°C
Soil temperature (Lockheed Model S1071)	(Counts - 400) 0.1	°C
Water level (Universal Engineering Systems Model T-66)	(Counts) 0.1524	cm
Water temperature (Lockheed Model S1071)	(Counts - 400) 0.1	
Water velocity (Kahl Scientific Model 232WA240)	V = 0.1254 (Counts/2) + 0.024	m/sec
Water-quality sensors (Martek)		
<u>a</u>. D.O.		
(1) Mark II	Counts (B_i/500)0.5 where B_i = range of D.O. and equals 5, 100, or 20 as set on D.O. display meter	mg/l
(2) Mark V	(Counts) 0.02	mg/l
<u>b</u>. pH		
(1) Mark II	(Counts) 0.012	Dimensionless
(2) Mark V	(Counts) 0.014	Dimensionless
<u>c</u>. Conductivity		
(1) Mark II	Counts (A_i/436.8) where A_i = range of conductivity to 100, 50, 25, 10, 5, or 2.5 as set on display meter	mmhos/cm
(2) Mark V	(Counts) 0.1	mmhos/cm
<u>d</u>. Temperature		
(1) Mark II	(Counts) 0.04	°C
(2) Mark V	(Counts) 0.045	°C
(3) Lockheed Model S1071 (see soil temperature		
Transmissivity (Martek Model XMS)	$\left[(\text{Counts})\ 0.2\right]^4$	Percent T for 1-m path length

Table 4

Summary of Performance of LEC Field Stations and Sensors

Location	Date	No. of Field Stations	Types of Sensors	Data Collection Interval min	No. of Days Deployed	No. of Satisfactory Records*	Error Rate, %	Types of Major Equipment Malfunctions
Pine Bluff Arsenal, Arkansas	9/74-5/75	2	(1) Solar radiation (incoming) (2) Wind speed (3) Wind direction (4) Rainfall (5) Soil temperature (surface and 30-cm depth) (6) Stream water level (7) Wier box water level (8) Water velocity (9) pH (Martek Mark II) (10) D.O. (Martek Mark II) (11) Conductivity (Martek Mark II) (12) Water temperature (Martek Mark II)	15, 30; 15, 30	240,200	125,120	48, 40	a. Field station power supply b. Field station timer c. Cassett tapes and drive motor for recording data d. Power supply for pH, D.O., and conductivity probes e. Contaminated probes f. Sensor signal-conditioning electronics
Fort Carson, Colorado (Red Devil and Turkey Creek)	11/75-5/76	2	(1) Rainfall (2) Wind speed (3) Wind direction (4) Air temperature (5) Solar radiation (incoming)	60, 30; 60, 30	174,174	171,118	2, 33	a. Solar panel b. Field station timer c. Field station power supply (no solar panel)
Fort Carson, Colorado (Clover Ditch)	11/75-5/76	1	(1) Rainfall (2) pH (Martek Mark II and V) (3) D.O. (Martek Mark II and V)	60, 30	113	70	38	a. Field station timer b. pH and D.O. probes and signal-conditioning electronics

(Continued)

* See paragraph 155 for definition of satisfactory record.

AD-A033 359 ARMY ENGINEER WATERWAYS EXPERIMENT STATION VICKSBURG MISS F/G 14/2
AN AUTOMATED SYSTEM FOR COLLECTING, PROCESSING, AND DISPLAYING --ETC(U)
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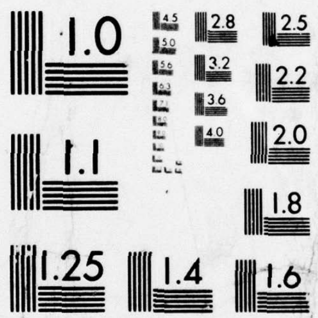

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Table 4 (Concluded)

Location	Date	No. of Field Stations	Types of Sensors	Data Collection Interval min	No. of Days Deployed	No. of Satisfactory Records	Error Rate, %	Types of Major Equipment Malfunctions
Fort Carson, Colorado (Clover Ditch) (Cont'd)	11/75-5/76	1	(4) Conductivity (Martek Mark II and V) (5) Water temperature (Martek Mark II and V)	60, 30	113	70	38	
Fort McClellan, Alabama	11/75-5/76	1	(1) D.O. (Martek Mark V) (2) pH (Martek Mark V) (3) Conductivity (Martek Mark V) (4) Water temperature (Martek Mark V) (5) Transmissivity (6) Rainfall	30, 60	149	106	24	a. Damaged pH and D.O. probes b. Contaminated probes (D.O., pH, and transmissivity) c. Field station timer
Upper Blakely Island, Mobile, Alabama	12/75-5/76	1	(1) Rainfall (2) Wind speed (2-m and 8-m heights) (3) Wind direction (2-m and 8-m heights) (4) Solar radiation (5) Soil temperature (surface and 1.5-m depth) (6) Air temperature (7) Pan water level and evaporation	15, 30, 60	134	92	31	a. Field station timer b. Cassette tape transport failure c. Failure of signal conditioning for sensors
Satartia, Mississippi	11/75	1	(1) Rainfall (2) Solar radiation (incoming) (3) Soil temperature (surface and 30-cm depth) (4) Air temperature (5) Wind speed (6) Wind direction	15	21	20	5	a. Radiation-sensor calibration problems

APPENDIX A: COST OF AUTOMATED FIELD STATION AND SELECTED ARRAY OF SENSORS

The costs (1 May 1976) of the WES field data acquisition system and a typical array of sensors that could be used for environmental monitoring of baseline conditions are given below.

LEC 101R 32-Channel Field Station = $13,000

Cables and Connectors for Sensors Listed Below = $3000

	Cost, dollars		
Sensor Type	Sensor	Signal Conditioning	Total
Solar radiation (Eppley)	1000	340	1340
Air temperature	150	250	400
Wind speed	400	220	620
Wind direction	400	220	620
Rainfall	230	220	450
Evaporation	700	250	950
Soil temperature	120	250	370
Water velocity	500	220	720
Water temperature	120	250	370
Water level	500	250	750
Transmissivity	3200	350	3550
Water-quality package (Martek Mark V)	2100	1400	3500
(a) conductivity (75)			
(b) temperature (95)			
(c) pH (295)			
(d) D.O. (195)			
(e) stirrer for D.O. (250)			

In accordance with ER 70-2-3, paragraph 6c(1)(b), dated 15 February 1973, a facsimile catalog card in Library of Congress format is reproduced below.

West, Harold W
An automated system for collecting, processing, and displaying environmental baseline data, by Harold W. West [and] Herman M. Floyd. Vicksburg, U. S. Army Engineer Waterways Experiment Station, 1976.
1 v. (various pagings) illus. 27 cm. (U. S. Waterways Experiment Station. Technical report M-76-11)
Prepared for Office, Chief of Engineers, U. S. Army, Washington, D. C., under Project 4A762720A896, Task 01, Work Unit 006.

1. Computer applications. 2. Data processing. 3. Environmental data. 4. Information retrieval. 5. Sensors. 6. Automated recording. I. Floyd, Herman M., joint author. II. U. S. Army. Corps of Engineers. (Series: U. S. Waterways Experiment Station, Vicksburg, Miss. Technical report M-76-11)
TA7.W34 no.M-76-11